Physics students' reasoning and argumentation when working with mathematical modelling problems

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Summary

The aim of the research

The aim of this research was to illuminate students' strategies and their ways of thinking while they are doing modelling exercises. The exercises were developed by Øystein Guttersrud (2008) to examine the skills of physics students in mathematical modelling of physical phenomena, their understanding of scientific thinking methods and also their understanding of multiple forms of representation in physics.
Comparing the qualitative results from the present study with Guttersrud's (2008)) quantitative research, may open a broader view of how important is the understanding of representation forms for understanding physics and physical phenomena.

The research method

This thesis provides the findings from 4 focus groups conducted with a total of 16 students studying physics at one upper secondary school. In this study, groups of students got three exercises which they solved collectively in the context of a focus group through which we wanted to evaluate their scientific ways of thinking and working. The focus group discussions lasted about one hour each. Focus group sessions were audio taped, transcribed and analysed with attention to different types of representational approaches, different types of content, different forms of student arguments, different types of argument, and different types of interchanging between representation forms

Principal findings

- Physics students sometimes don't have enough knowledge about some basic physics concepts and this can be a reason that they can't use those concepts correctly during solving the physics problems. Sometimes students have enough knowledge about physics concepts, but they just can't put them into words and this leads them to difficulties during problem solving.
- Physics students have also some problems with interchanging between different representation forms. One reason can be that they lack enough knowledge about these representation forms which are very important in representing different physical phenomena. Another reason can be the lack of knowledge of how these representation forms are related to each other.
- Students have sometimes difficulties in translating between mathematical and physical languages. This can also be related to lack of enough knowledge about physics concepts or can be related to the lack of enough knowledge in mathematics or can be related to the lack of knowledge of relation between mathematics and physics.
- Student discussion during solving physics problems shows that they often don't argument enough for their answers or don't use enough scientific reasoning during solving physics problems.

Main conclusions

- Physics teachers should emphasize mathematics in their teaching process.
- Teachers should be instructed in how to teach students mathematics in physics and the language of different representation forms.
- Students should learn translation of mathematics' language in physics.
- Students should learn about representation forms and the advantage of interchanging between them to understand physics better.
- Students should learn skills of argumentation and reasoning and they should have practice in this area in the classroom situation.

Contents:

1 Background and theory

1.1 Introduction and aims

The central part in physical science is developing and applying mathematical models of physical phenomena. Handling, analysing and interpreting data are essential parts of the practice of science in many areas and therefore, understanding modelling is an important skill for citizenry (Guttersrud, 2008). According to Dolin (2002) it is also important in physics education that students' mathematical modelling competency get developed. Dolin (2002) has also suggested, based on Roth (1995) that physics appears difficult as it requires students to deal with interchanging between multiple forms of representation as conceptual, mathematical, graphical, experimental and pictorial representations.

There is a belief that engaging in argumentation leads to more secure understanding of pre-existing concepts, but also allows students to hear new ideas that extend their existing knowledge and possibly eliminate misconceptions (Cross, Taasoobshirazi, Hendricks, & Hickey, 2008). Therefore, it is at the same time important that students engage in argumentation and develop their argumentation and reasoning skills to understand science better. The importance of the role of discourse in learning has been obvious in research works in the field of science education for a long time (Driver, Newton, & Osborne, 1998; Mortimer & Scott, 2003). In this study, evaluation of students' thinking and reasoning about scientific concepts, especially mathematical models and modelling, is one of the focus points.

With having these important points in mind, this qualitative research was performed with students who took physics course (2FY) in Norwegian upper secondary school during spring 2007.It is based on findings from the Norwegian research project, PHYS21 "Physics for the 21st century" (Angell, Henriksen, & Kind, 2007), performed by the Physics education group at the Department of Physics, University of Oslo, which utilized multiple representations of physical phenomena as a framework for implementing *empirical-mathematical modelling* in upper secondary physics and on Guttersrud's Phd project that was a part of PHYS21. Guttersrud (2008) developed a test of mathematical modelling competency. Three problems from this test have been used in this study. The students in the focus groups were supposed to discuss and argument about those problems and their discussions was recorded with the purpose of being analysed afterwards.

The aim of this study is to examine how physics students talk, argue and reason in groups while they collaboratively solve mathematical modelling problems.

In this study I am going to investigate how physics students approach mathematical modelling problems and how they work collaboratively to solve such problems.
In order to approach this investigation several perspectives from science education theory and research are of relevance. In this introduction, I will look into:

- Norwegian school physics
- The PHYS 21 project
- Reasoning and argumentation
- Multiple representation forms in physics
- Models and modelling in physics and physics education
- Nature of science (NOS)

1.2 Norwegian school physics

If we want to get better results from physics courses in Norwegian schools, in first stage we have to ask ourselves about what is known about school physics.

1.2.1 FUN

In order to address the recruitment crisis in physics in Norwegian upper secondary school a study began at the University of Oslo, named FUN. FUN is abbreviation for physics education in Norway (Fysikk Utdanning i Norge) and has been undertaken by the Department of Physics and Institute for Teacher Education and School Development. The research was carried out by Carl Angell, Ellen Karoline Henriksen and Anders Isnes. They constructed a questionnaire study in 2000 to find out how students and teachers in secondary education, and university students, view physics and physics instruction.

The FUN-study ("Fysikkutdanning I Norge": Physics Education in Norway (Angell, Guttersrud, Henriksen, & Isnes, 2004)), investigated factors that influence students to choose or not choose physics subject. This project at the same time evaluated what students and teachers mean about physics. Results from this study provided an overview of how students and teachers perceive school physics and what they regard as important and what aspects find student challenging.

The study showed that 40% of girls and 27% of boys who had physics2 subject didn't think to get physics3 subject afterwards. The question here is that why most of students don't want to study in physics field in higher degrees or even in upper secondary school. The answer of this question goes back to contents of physics and teaching methods in physics.

Results from FUN showed that upper secondary school students saw physics as interesting, but demanding and work- intensive. Students may have some trouble with mathematics, but they didn't admit it directly.
In relation to the question of "what physics is" most of the students and teachers had a description of it as "understanding the world". Regarding the quality of physics instruction, secondary school students were generally satisfied and they indicated that they would like discussion and "qualitative instruction approaches" to be applied more frequently.

Based on findings from FUN it is suggested that physics education in upper secondary level should aim at variety, in instructional approach, integration of mathematics on the physics courses, more pupil-centred instruction, and a stronger emphasis on knowledge in context to prepare pupils for tomorrow's society.

1.2.2 The Norwegian physics curriculum

In the former version of Norwegian science curricula (L97, 1996), literacy was a major concern. At the same time in upper secondary physics curricula, the literacy concern was in most cases more weakly expressed. The Norwegian physics curriculum has a traditional academic form. It means that the curriculum functions as a subject preparing for higher education in physics or engineering. In the latest Norwegian Physics curriculum (Utdaningsdirektoratet, 2006), the main focus is on understanding of nature, technology and phenomena in everyday life. According to this curriculum physics lessons should contribute physics students to employ mathematics in physics and the use of mathematics for modelling of reality in physics. Among the skills which students are meant to have with them after physics2 is to be able to read and understand tables, diagrams, graphs, mathematics equations. This study can give suggestions about what considerations have to be made during physics teaching.

1.2.3 Modelling in the Norwegian physics curriculum

In the present physics curriculum (Utdaningsdirektoratet, 2006) there are some goals of learning physics that include modelling under the heading "To describe nature with mathematics":

Physics 2

- *"Beskrive banen til en partikkel ved hjelp av parameterframstilling, og bruke derivasjon og integralregning til å regne ut posisjon, fart og akselerasjon når en av de tre størrelsene er kjent.*
- *Analysere ulike matematiske modeller for en fysisk situasjon, med og uten digitale verktøy, og vurdere hvilken modell som beskriver situasjonen best"* (Utdanningsdirektoratet 2006,s.2)

Physics 1

- *"Bruke parameterframstilling til å beskrive rettlinjet bevegelse for en partikkel, og bruke derivasjon til å regne ut fart og akselerasjon når posisjonen er kjent, både med og uten digitale verktøy*
- *Lage en eller flere matematiske modeller for sammenhenger mellom fysiske størrelser som er funnet eksperimentelt*
- *Bruk matematiske modeller som kilde for kvalitativ og kvantitativ informasjon, presentere resultater og vurdere gyldighetsområdet for modellene"* (Utdanningsdirektoratet 2006,s.2)

In general part of curriculum (Utdaningsdirektoratet, 2006) it is also important that students be able to express themselves orally and in written form and this is about all kind of subjects, including Physics:

"<u>Å kunne uttrykke seg muntlig og skriftlig</u> i fysikk innebærer å beskrive egne observasjoner og erfaringer fra naturen, eksperimenter, ekskursjoner og informasjon i medier. Å formulere spørsmål og hypoteser og å bruke fysikkfaglige begreper og uttrykksformer inngår i dette. Det betyr å argumentere for egne vurderinger, gi tilbakemeldinger og presentere resultater. Det vil si å beherske et presist og entydig språk, blant annet å skille mellom dagliglivets bruk av begreper og fysikkens bruk av de samme begrepene." (Utdanningsdirektoratet 2006,s.3)

In this study, as named (see 1.1), it is a goal to see how students argument during working with physics problems.

According to curriculum the point that students should be able to translate different presentation forms (see 1.10) is a goal of learning Physics at Norwegian schools, but the word "representation form" isn't used directly in curriculum:

"Å kunne lese I fysikk innebærer å trekke ut, tolke og reflektere over informasjon i fysikkfaglige tekster, brosjyrer, aviser, populærvitenskapelige magasiner og bøker og på Internett. Det betyr å forstå bruksanvisninger, tabeller, diagrammer, symboler og fagspesifikke tekster. Videre vil det si å forstå innholdet i tabeller, grafer, bilder, ordinær tekst og likninger." (Utdanningsdirektoratet 2006,s.3)

1.3 Project PHYS21

"Physics for the 21st century" (PHYS21) is a project that took place over a period of three years by Øystein Guttersrud and school-laboratory in the Department of Physics, University of Oslo. This project was an attempt to implement modelling in the upper secondary physics curriculum. The aims of this project were to give students understanding about models and modelling and to give students practice in doing modelling, preferably without knowing the "correct answer", and to encourage students to use and interchange between different forms of representation (Angell, Kind, Henriksen, & Guttersrud, 2008b).
PHYS21 used multiple representations (see section xx) of physical phenomena as a framework for implementing empirical-mathematical modelling in upper secondary physics. In PHYS21 a written test was developed to assess students' modelling competency, measured as their abilities to reason scientifically and interchange between multiple representations of physical phenomena (Guttersrud, 2008). There were about 20 physics teachers who participated in initial phases of the project and the last (full implementation) year participants included 6 schools, 13 teachers and 289 students. The test was given to a total of 446 PHYS21 and regular physics student in 2005, and some response distributions from this test will be presented in this thesis.

A teacher booklet and a similar booklet for students were produced with these contents:

- The view of physics applied in the project
- Aspects of scientific method and scientific reasoning
- Examples of scientific models and the modelling process
- Suggestions for student modelling activities

The curriculum which was used in this project was a little changed version of the ordinary national curriculum with replacement of *modelling* instead of one out of eight stated attainment targets (thermo physics).The idea was to teach modelling as a line during the course. The important point was that teachers involved in PHYS21 was going to teach *about* modelling in physics, as well as teaching students *to do* modelling. The emphasis in PHYS21 was on:

- Making clear to students the various representations and the transitions between them
- Helping the students developing a perspective on their own understanding and learning and possibly refine their learning strategies in physics
- The relationship between mathematics and physics
- Scientific reasoning related to experimental results, by proposing hypotheses and testing them out experimentally

This project was an attempt to introduce the model- like nature of scientific knowledge and the ways in which predictions are generated and observations are evaluated in terms of standard theories to the students, as Leach (1999) recommended. He pointed out that many students are unable to evaluate the logical implication of data for knowledge claims.

1.4 Tests used in Guttersrud's thesis

The tests I have used in this study are three units selected of the written modelling test which Øystein Guttersrud had developed in his research. In his study there were total seven units including 33 items. The problems used in his study were tested by him and this test showed that the problems discriminated clearly between the competent and the less competent students. The PHYSAP (the PHYS 21 student assessment program) achievement test (Guttersrud, 2008) was based on views and ideas central to project PHYS 21. So these tests were developed with the purpose of connecting content areas as science and mathematics while integrating scientific reasoning and multiple representations of physical phenomena in the problem solving strategies. The PHYSAP has used both closed questions and selected response items and open-ended questions. In Closed questions respondents select the alternative most appropriate according to their view. Closed questions are of two types: either respondents choose from the four alternatives they have been given in the question or they have to agree or disagree with a set of assertions presented in a table.

In the present study have been used three units from the PHYSAP achievement test: The car, Sea Level and Wind power.
The first unit is chosen because students at 2FY courses were supposed to have learned about speed, acceleration and mathematical formulas related to them, in their lessons and it was interesting to see how they discuss it since they are supposed to have pre- knowledge in this topic.
The second unit is about studying melting of ice and its influence on sea level .This unit is specially chosen because Global warming and smelting of ice around the Poles are an interesting topic nowadays.
The third unit is about producing electric current with using a windmill. This unit has been chosen because here students are confronted with testing "hypotheses" and it was interesting to observe how students argue about whether to keep or not keep a hypothesis.
The teachers who took part in the main part of PHYS 21 had mentioned that it was difficult for them to focus on mathematical modelling approach in other themes rather than mechanics (Angell et al., 2008b) Using problems with different types of themes can show to students that it isn't just mechanics problems which includes modelling or explicitly mathematical or empirical-mathematical modelling.

1.4.1 Type of items in Guttersrud's thesis

In Guttersrud's (2008) test, each unit was made up of a stem and 3-5 items related to the theme of the stem. There are used four types of item formats in his work. In the figure 1.1, the first type of "selected response items" is "vector items". Vector items ask students to agree or disagree with a set of assertions presented in the table. These vector items may consist of two or more *true-false items* according to Downing (1992) and may according to Frisbie (1992) be referred to as *multiple true- false* items. In such items students are supposed to select one out of two given choices for each assertion: "yes"/"no" or "agree"/"disagree" etc. The second type of selected response items is the "multiple choice item" (MC) which offers some alternative for the students to choose from. The first type of "constructed response items" is "short constructed response items" which students respond to by writing a single word or number (see question27 in Appendix 1). The second type is "extended constructed response item" where students typically have to write an answer over one or more lines in their own words (see question 13 in Appendix 1). Table 1 shows the items constituting Guttersrud's (2008) achievement test is distributed evenly across the different formats.

Table 1.1: *different formats of Guttersrud's (2008) achievement test items.*

Classes	Formats
Selected response	Vector
	Multiple choice
Constructed response	Short constructed response
	Extended constructed response

1.4.2 Types of reasoning in Guttersrud's items

In this part, it would be useful to introduce the five reasoning process categories which Guttersrud (2008) have used in the scientific reasoning dimension of his study to separate the reasoning skills of students during solving the problems:
Items covering the first two reasoning processes, "categorize" and "identify/apply", which include kind of problems students are expected to "recognize". The category "identify/apply" is different from the category "categorize" in the way that the latter introduce quantitative reasoning. But at the same time these two named categories are a part of analogous type because in both of them students are assumed to be capable to solve the problems in view of prior experience with analogous situations. The other three reasoning process categories, "decide"; "evaluate"; and, "conclude and communicate", are characterized as analytic. The reason is that in this type students must decide e.g. whether or not cause and effect relationships or sufficient conditions are present.

Table 1.2: *Scientific reasoning processes assessed by PHYSAP in Guttersrud's (2008) project.*

Type	Process	Description
Analogous	Categorize	Categorize diagrams, experiments and type of experimental error in relation to information provided.
	Identify/apply	Identify shared properties of physics formulas (e.g. linearity). Apply knowledge and general mathematical expressions to describe physical phenomena. Plot experimental data.
Analytic	Decide	Select from alternative solutions and explanations with respect to empirical data and evidence provided.
	Evaluate	Evaluate scientific claims with respect to empirical data and evidence provided.
	Conclude and communicate	Draw and communicate valid science-based conclusions anchored in empirical data and evidence provided. Make and communicate scientific explanations to justify solutions.

1.5 Reasoning and argumentation

Since the main goal of this study is to observe how the students reason and argument during working with mathematical modelling exercises, it is necessary to understand what we mean by “reasoning” and “argumentation”, what is their role and functions within science and what is their place in science education.

To reason means “to draw inferences appropriate to the situation”. Reasoning is the cognitive process of looking for reason and beliefs, conclusion, actions and feelings (EncyclopædiaBritannica, 2008).

In philosophy there are two different forms of reasoning which may be used to support or justify conclusions.

Deductive reasoning: Deductive arguments have a valid reasoning in their content. The condition which is required a reasoning to be valid is that the argument’s conclusion must be true when the premises are true.

Inductive reasoning: This form of reasoning contrasts strongly with deductive reasoning. In this form the truth of the premises does not guarantee the truth of the conclusion. Instead, there is a degree of probability in the conclusion of an inductive argument.

A third form, **Abductive reasoning,** often involves inductive and deductive arguments. In this reasoning there is an attempt to favour one conclusion above others. Two usual ways to gaining just one conclusion are:

- By attempting to falsify alternative explanations
- By demonstrating the likelihood of the favoured conclusion, given a set of more or less disputable assumptions

First, I consider it essential to examine what is meant by “argument”. When a distinction was made between the study of logic and the study of how people in specific situations actually reason from premises to conclusions, the field of argument studies came up. Logic is seen as an academic discipline that presents decontextualized rules for relating premises to conclusions, but arguing is a human practice situated in specific social settings. Argument can be seen as a *social* activity taking place within a group and can also be seen as an *individual* activity, through thinking and writing (Driver et al., 1998).

Within the field of science education, researchers have recognized the importance of the role of discourse in learning (Mortimer & Scott, 2003) and it has been more focus on engaging students in scientific argumentation, where students are proposing, supporting, criticizing, evaluating, and refining ideas about scientific subjects (Driver et al., 1998). Argument and the argumentative practice are seen as a core activity of scientists and have a central role in science education. To enhance the public understanding of science and improve scientific literacy, argumentation in education *about* science and *in* science must be given a high priority (Driver et al., 1998)

The meaning of argument in the educational literature has two perspectives. One of them is according to the Encyclopædia Britannica (2008),“advancing a reason for or against a proposition or course of action.” This kind of arguments is common in science lessons in which a teacher comes with a scientific explanation to a class or to a group of students and helps them to see it reasonable. The second interpretation of argument is “dialogical” which involves when different perspectives are being examined and the purpose is to reach agreement on acceptable claims or courses of action (Driver et al., 1998)

There are three different arguments for enhancing argumentation skills(Aufschnaiter, Erduran, Osborne, & Simon, 2007):

- Scientists engage in argumentation to develop and improve scientific knowledge
- The public has to use argumentation to engage in scientific debates
- Students’ learning of science requires argumentation

In this study the third argument is important and is going to be discussed more specifically.

Although the substantial researches indicate the benefits of argumentative discourse, in related to actual science classrooms it isn’t often incorporated (Driver et al., 1998).The main reason is that scientific concepts are often presented as a set of known facts that students are required to memorize (Cross et al., 2008). In other words, in schools science is portrayed by a “positivist perspective” which says science is a subject with clear “right answers” and in this subject data lead to agreed conclusions. According to Norris (1977) When science is introduced as simply as process of memorizing facts and concepts to students, it gives them an inaccurate view of how science is actually practised, and devalues the ideas and thoughts of the individuals receiving the information. Science education, therefore should not only involve transmitting a set of known facts to students, but should also focus on encouraging students to engage in critical thinking about science concepts, supporting their claims using evidence, and justifying their ideas with practicable explanations (Cross et al., 2008).
Simon (2006) means it is useful to distinguish between “arguement” and “argumentation”. According to him argument refers to the substance of claims, data, warrants, and backings that contribute to the content of an argument; at the other hand argumentation refers to the process of assembling these components. In this relation to providing students with tasks that require discussion and debate gives an opportunity to teachers to engage students In the construction of arguments through the process of argumentation (Simon et al., 2006)

1.6 A socio-cultural view of learning

The epistemological paradigm based on constructivism believes individuals construct personal realities which make sense to them (Davis, McCarty, Shaw, & Sidani-Tabbaa, 1993). In science education “constructivism” has been used to describe learning. According to Guttersrud (2008), in the science education community the idea of personal constructivism has been replaced with a social constructivist or an approach by Vygotsky.
In this approach ideas are expressed through inter-subjective processes using a language the participants have been socialised into.

Sociocultural theory has a major focus on how social discourse gives rise to the development of mental functioning in individuals. Main figures in this theory were L. S. Vygotsky and M. M. Bakhtin (1934) who had major efforts in developing this theory. Vygostky brings attention to the primary importance of talk in social situations, as a necessary precursor to individual learning. In Vygotsky’s perspective the main idea is that development and learning involve a passage from social contexts to individual understanding. With other words, an individual first meets new ideas in social situations where those ideas are rehearsed between people,

drawing on a mode of communication, such as talk or discussion. According to Vygotsky the interaction is existed on the social plane. The social plan may involve a group of friends or classmates talking. Ideas which are rehearsed during the social event are able to be reflected on each participant. This can be translated as transition from social to individual planes. During this transition process the social tools for communication become internalized and provide the means for individual thinking. Vygotsky means that it is necessary to look beyond the individual mind to study learning, and that the external world of the learner and how the learner interacts with that world is the primary site in which learning occurs (Cross et al., 2008).
According to Bakhtin (1934), the fundamental point is that meaning making is a dialogic process, which means bringing together and working on ideas, the process which has been tried in this study to find out the process of thinking and learning.

In this study we evaluate approaches based on cognitive- constructivism by seeing how students' pre-knowledge influence their learning and discussions. At the same time here we use methods based on social constructivism idea by observing the interaction of students with others during argumentations in focus group studies.

1.7 Learning strategies

Learning strategies are the processes that underlie performance on thinking tasks(Nisbet & Shucksmith, 1986) and are essential in students' processing of new knowledge(Guttersrud, 2008). There are different techniques that a learner can be thought to use during learning that are referred to as learning strategies.

There are different meanings about learning strategies. One model that Barker (1989), based on generative learning model of Osborne and Wittrock (1985) which lies within the constructivist theory, has used at his work. The model postulates that learning is an outcome of an interaction between existing ideas and sense information actively selected and attended to. According to Barker (1989) learning involves generating links between these two and hence actively constructing meaning. This learning strategy has been used by the students in the present study where the students linked their knowledge to the new information and data from the problems trying to solve them. The students also meet new ideas during the discussions, which is a social situation as is defined in Vygotsky's theory, and they combine it with their own ideas to take conclusions and learn more about the topic they are talking about or to construct new meanings.
Memorizing is also a strategy that the students used a little bit in present study. They tried to memorize the experiments they had during their physics course.

1.8 Physics education

A coherent course of study in the fundamental science of physics must reflect the nature of subject itself, presenting physics both as a process and as a structure. The process is one of concept development and model building; the structure is provided by an interconnected fabric of ideas (Wenham, Dorling, Snell, & Taylor, 1972).

In a more general perspective there are three essential questions in physics education: What? Why? And How? (Sjøberg, 2007).

The question of "**What?"** has different aspects: What are actually the main problems of the subject? What is the stable part and what is changeable inside the subject? Most subjects consist of infinite knowledge and we have to decide what is important and what is that has a small degree of importance in learning and teaching the subject

The question of "**Why?"** is about the grounds of the subject. Why is this subject important that we have to have it in all school years?

The question of **"How?"** is about the methodology of the subject. How subject materials will be organized and presented to get the best result that is the learning of subject by students. According to Sjøberg (2007), we can not get reasonable answer to these three questions without identifying who the student is, which school and which society we have in our minds. This thesis is a study about the third question, "How?" and some how the first question about "what?". With studying about how students handle the exchanging of different representation forms in solving physics exercises it would be easier to decide "what" should students been taught and which teaching methods should be used in teaching them those decided subjects in physics to get better results in teaching physics students in upper secondary school.

1.9 Multiple representation forms in physics

According to Guttersrud (2008) developing and comprehending models of physical phenomena involves working with multiple representation. *Multiple representations*, in his research refer to the representation of a physical phenomenon using different forms of representation (e.g. graphical and mathematical) or different versions of a representation (e.g. graphs showing speed and acceleration as functions of time).

Dolin (2002) has suggested, based in Roth (1995),that physics appears difficult because it requires to cope with a range of various forms of representations (experiments, graphs, verbal descriptions, formulae, pictures/diagrams)
Here is an overview over the five representation forms based on Guttersrud (2008):

Table 1.3: *Forms of representation assessed by PHYSAP in Guttersrud's (2008) project.*

Graphical representation	Refers to graphs and other descriptive representations of variables
Pictorial representation	Refers to all kinds of figurative descriptions except graphs.
Mathematical representation	includes equations and the mathematical operations on these
Conceptual representation	Deals with the concepts used to describe phenomena inclusive verbal descriptions of phenomena using scientific concepts.
Experimental representation	Refers to all practical approaches

According to Prain and Waldrip (2006) “multiple” representation refers to the practice of re-representing the same concept through different forms, including verbal, graphical, and numerical modes. Representation forms in this study are used to describe phenomena in physics. Particularly, mathematical representation form has been used successfully for centuries to describe physical phenomena.

Dolin (2002) means the challenges of interchanging between multiple representation forms and skills in understanding and translating of them results in that students perceive physics as a hard and demanding school subject. “Translation” between different representation forms means being able to recognise conceptual links between representations (Prain & Waldrip, 2006). Scientists have to be able to interpret all of these forms effectively and are able to integrate and translate among them. As a result, a possible instructional goal is to introduce the representational facility to science students and encourage them to use it (Kohl & Finkelstein, 2005)
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1.10 Models and modelling in physics

According to A. Einstein, “Science is not just a collection of laws, a catalogue of facts. It is a creation of the human mind with its freely invented ideas and concepts actually physical theories try to form a picture of real life and to establish its connection with the wide world of sense impressions”(A.M.A, A.S.E., & A.A.M., 1970).

Hestenes (1987) means model is an adoptive object, a conceptual representation of a real thing. The models in physics are mathematical models and with other words in the models physical properties are represented by quantitative variables. He also describes modelling or model developing as the cognitive process of applying the design principles of the theory to produce a model of some physical object or process (Hestenes, 1987).
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Scientific practice involves the construction, validation and application of scientific models, so students should be engaged in making and using models. A phenomenon observed in nature may be represented in different ways in physics. Modelling is a fundamental process in physicist’s study of nature. When we have a physical situation we wish to understand, modelling is the main tool we can have advantage of to learn and understand it better. The Process in understanding is making, analysing and evaluating a model for the situation. To learn science, students must engage in all aspects of modelling (Hestenes, 1996). PHYS 21 is built on the view that modelling is an essential process in the study of nature by physicists, and therefore should play a natural and important part in the learning process of physics students. The reason that *models* and *modelling* get increasing attention from science education community as important components of a contemporary science education is that it reflects the nature of physics and at the same time modelling activities are considered useful for learning physics concepts and processes (Angell, Kind, Henriksen, Guttersrud, & 2007).

Hestenes (1996) means the traditional physics courses has problem solving as a heavily emphasised part in their teaching process and this directs student attention to problems and their solution as units of scientific knowledge. Modelling theory has more emphasis on models rather than problem solving unit. Even though problem solving is important, it should be in subordination of modelling (Hestenes, 1996).According to him, since the various modelling modes make a variety of problems, so problems can be classified according to their roles in the modelling processes. In other word the model provides the solution to the problem and a single model can solve many problems.

An important component in a modelling approach to physics education is to give students an understanding of reasoning as an essential mediator between experimental observations and theory/model, strengthening the connection between experimental and conceptual representations (Angell, Kind et al., 2007).
Making students able to employ multiple representations to construct models of physical phenomena is also an important part of modelling in physics education (Guttersrud, 2008).

1.11 Nature of science

The concept of the nature of science (NOS), has typically been referred to as the epistemology of science, science as a way of knowing, or the values and beliefs inherent to development of scientific knowledge. The important point to notice is to know that the NOS isn't the same as science processes(Adb-el-khalick, Bell, & Lederman, 1998).
From an educational perspective it is agreed that teaching the students to recall scientific facts, laws, and theories is not enough. Rather, it is important for students to know why scientific knowledge and ideas have merit and may be trusted. Bell (2003) means by knowing the characteristics of scientific knowledge and the way it is constructed, , it will be easier for citizens to distinguish good science from bad, and apply scientific knowledge to their everyday lives.
Zeidler (2002). try to emphasize the importance of scientific literacy and its relation with nature of science with sentences below:

> *"If teachers support the notion that scientific literacy entails, at least in part, the ability of students to engage in active dialogue as they ponder evidence, apply critical thinking skills, and formulate positions on various topics, then informal discussions and formal debates that challenge students to use multiple views and competing evidence in rendering decisions becomes central to a broader view of scientific literacy that explicitly includes aspects of the nature of science".(Zeidler et al.2002,p:344)*

He suggests that one of the goals of nature of science instruction should be the elicitation of students' misconceptions by engaging students in socio-scientific reflective thinking activities and engaging them in discussions on socio-scientific topics where students can challenge one another's beliefs.
According to Guttersrud (2008) an empirical-mathematical modelling approach to teaching physics has potential to give the students meaningful views on the nature of science.

In this research the main focus is on empirical- mathematical modelling approach and reasoning processes which both are important for learning of NOS.

1.12 Research questions

Based on the perspectives in the previous sections, the main aim of this thesis (to examine how physics students talk, argue and reason in groups while they collaboratively solve mathematical modelling problems) may be broken down to the following research questions:

1. To what extent did students use physics knowledge during argumentations?
2. To what extent did students use mathematical knowledge in their argumentations?
3. To what extent did students use just one representation form?
4. To what extent did students use interaction between different representation forms?
5. To what extent did students use correct or wrong scientific idea?
6. To what extent did students use the different classes of the scientific social language?
7. To what extent did students use the different types of talk?
8. How did the students react on this kind of exercises?

These questions show what is going to be evaluated by this study. These topics were the most interesting ones in related to the discussion which students had in focus group studies. The most important points were the students' meanings and the way of expression of these meanings. A qualitative research method was used to analyse the focus groups discussions to get the answers of these questions.

2 Method

2.1 Introduction

The main aim is to find out how students reason and argue when working with mathematical modelling exercises. The starting point is the problems developed by Øystein Guttersrud and a simple analysis of responses to the written test. The main part of this present work was a qualitative analysis of students' discussions while solving the same problems in groups.

2.2 Focus groups

The first part of the focus group discussions in this study was more structured than usual in focus groups, since it consisted of students' discussion of physics tasks. The second part in the other hand was more like traditional focus group discussion where the participants got invited to share their experiences with the modelling problems and to offer their views on physics in general and modelling in particular. Therefore, it has been chosen to call this study a focus group study. One of reasons for this choice was that this part of study resembled a semi-structured group discussion which has ca.4-6 participants. In the present study, the data from focus groups is going to be compared with the quantitative data from Guttersrud (2008) and helps us to gain increased insight into students' thinking methods and their understanding about representation forms and their attitudes toward physics in general

2.2.1 Definition of focus groups

Focus groups are group interviews. A small group, 4 -12 participants, discusses the topics that the interviewer raises during the interview. The essential data in focus group study are what the participants in the group say during their discussions. Focus groups study is a qualitative research method (Morgan, 1998).In qualitative research, we are open to different ways of seeing and analysing the world (Krueger, 1998c).In focus groups we use group discussion to generate the data and this distinguishes focus groups from any other form of interview. In focus groups study we have an interview on a specific topic, which is where the word 'focus' comes from.

2.2.2 Advantages and disadvantages of focus groups

In focus groups we learn a great deal about the range of experiences and opinions in the group, even though we do not learn that much about each specific individual (Morgan, 1998). Since the amount and range of data are increased by collecting from several people at the same time in focus groups, this is a highly efficient technique for qualitative data collection. At the same time, group dynamics help in focusing on the most important topics and it is fairly easy to assess the extent to which there is a consistent and shared view. On the other hand, the results of focus group study cannot be generalized as they cannot be regarded as representative of the wider population. A particular problem with focus groups study is when one or two persons dominate. Analysis of focus group data is different from analysis of data collected through other qualitative methods and this means there are new challenges waiting for researchers.

2.2.3 Recruiting of focus groups

Recruiting process is always an important phase of focus group study. In focus group if you want to produce a decent discussion, you need to have right people. According to Morgan (1998) it is necessary to contact potential participants directly and follow-up contacts to ensure that people will attend. Since one of the aims of this study is to compare results from this study with Guttersrud's (2008) results from written modelling tests, in this study the goal was to recruit students who were taking 2FY subject, to taking part in four focus group interviews. Students were recruited to focus group studies by asking a 2FY teacher in upper secondary school early in 2007.
The main difference between participants in this study with those who were involved in PHYS21 was that in PHYS21, some of students had a special curriculum emphasizing both the empirical-mathematical modelling process and epistemological perspectives as on physics as model but in this study the students had the regular curriculum and had not been introduced to the modelling idea before the focus group study. Actually there wasn't any possibility to have students with the special curriculum since it was a long time ago that PHYS21 was over and maybe in this way this study gives us a chance to compare students who had been familiar with mathematical modelling in PHYS 21 with students here who haven't heard about the word "modelling" directly before beginning of doing the exercises in focus group study.

2.2.4 Number of focus groups and participants in each focus group

Four focus group sessions were conducted in this study. The first Focus group had five participants. For practical reason the number of participant got reduced to four in each group. Because of sickness of one of students the third focus group was held with three participants. All together there were 16 2FY students were involved in focus group studies including 10 boys and 6 girls. They were all from the same school and the same class. The focus groups were held in a classroom at their school. It was a familiar place for the participant and it made it easier for them to focus on the group discussions. Because of time limitation there wasn't possibility to use more focus groups. Focus group sessions lasted for about 60 min and they were audio-taped with the permission of participants and were transcribed after each session. It was an advantage having only 3-4 participants. With having not many participants it is easier for the researcher to follow the logic of the discussion.

2.2.5 Role of moderator

The role of moderator is to guide the discussion and listen to participants talking. Moderator should lead to a focused discussion and at the same time be aware to not participate, share ideas or engage in the discussion of focus group interview. Moderator is involved in a complex process of generating and analysing data, therefore moderating can be difficult (Krueger, 1998b).Moderating needs high concentration on the subject which is easy to perform when there is a one-to-one interviews. But in the focus group, the interactions of subjects result in even more complexity.

In this study I, as moderator on one hand I decided to not interrupt discussions as I wanted the discussions to be as natural as possible or with Morgan's (1998) words, a free-flowing discussion that follows the participants' interests. With interrupting the discussions there was a chance of giving the students some hints about the answer of following questions by saying anything that maybe actually was meant to just lead the students to get on the right track. On the other hand I tried to be positive and showed to participants that I respect them and I am an active listener .I had a complete presentation of myself and had some small talking with students to make them feel comfortable. I had also a description of the project I was working on at the beginning of each focus group interview to get them understand why they were there. I recorded all the discussions on the cassette tape recorder. I had video camera in two of the interviews to see if it helped me during transcription process (however, I didn't analyse directly the data I had got from video records).

2.3 Construction of interview guide

We can make distinction between types of interviews based on the degree of structure or standardization of the interview (Robson, 2002).According to Robson we have three styles of interview: ,fully structured interview, semi-structured interview and unstructured interview.

A fully structured interview has predetermined questions with fixed wording, usually in a pre-set order. The only essential difference between a fully structured interview and an interview-based survey questionnaires is the use of mainly open- response questions in the fully structured interview guide.

Semi-structured interview has predetermined questions which are modifiable by interviewer based upon the interviewer's perception of what seems most appropriate. In this type, particular questions which seem inappropriate with a particular interviewee can be omitted or there can be some additional questions.

In unstructured interviews, interviewer has a general interest area, and lets the conversation develop within this area and it can be completely informal.
In fully structured interviews the content of the discussion is under control by the questions in the interview guide.

A fully structured interview guide has been used in this study. Since the aim of this study is to "compare" students' experiences with using multiple forms of representation during modelling tasks and their views of hypotheses, laws and theories, so using a fully structured interview guide was the best option to get this aim.

The interview guide in the focus groups described here was developed based on the research questions, and it may be found in Appendix 3. A pilot testing was conducted to evaluate how the interview guide worked and to see if the questions were understandable for the students. The pilot test was done successfully and it showed that the interview guide is suitable to the conditions and was able to give us what we need of data.

2.4 Analysis

In his research, Guttersrud (2008) developed a coding system based on students' answers to the written test. These results were analyzed quantitatively using the statistics program SPSS (Statistical Package for the Social Sciences) by him. As a part of this work I'm going to discuss the qualitative results from the focus group studies in relation to the quantitative results from Guttersrd's (2008) study with 446 students.

2.4.1 Qualitative analysis

Qualitative research involves analysing and interpreting texts and interviews in order to give a meaningful description of a particular phenomenon (Auerbach & silverstein, 2003). In qualitative analysis we have to be good listeners. Openness to new ideas, approaches, and concepts is essential in qualitative analysis. Finding patterns, making comparisons, and contrasting one set of data with another perhaps are the most useful strategies in qualitative analysis. The qualitative analysis has an inductive character, for that reason researchers are the central agents in the analysis process(Lofland, Snow, Anderson, & H.Lofland, 2006).

According to Lofland (2006) although the qualitative data analysing program facilitates the analysis, the researchers still have to make the key decisions regarding appropriate conceptualizations and theoretical connections themselves. In this study, this has been done with going through the data and trying to find some connections between theory and the data constantly.
The other two points which are important in Lofland's (2006) opinion in relation to qualitative analysis are: comparing items under analysis constantly and being in contact with others interested in the project to clarify in researcher's own mind what it is that he/she is trying to get at. I've had these suggestions in my mind during analysis process and compared between focus groups and between qualitative and quantitative data and was in contact with others in my group in related to this study, constantly.

2.4.2 Analysing of focus group study

Focus group analysis uses many qualitative analysis methods and approaches (Krueger, 1998c). It can be difficult for the researcher to separate his/her personal view from what is said by participants, therefore being open to new ideas, approaches, and concepts can be helpful. Under this framework it is imperative that researcher be "objective" that means not allow his or her values to enter into the research process. In this model of research the scientist remains "objective" to gain a "true" understanding of reality (Hesse-Biber & Leavy, 2006). With this in mind I tried to get a true understanding of the meaning of students in related to their answers by going through their responses and rereading them several times and trying to see them with a wider point of view and not letting my own ideas influence my conclusion from what they say.

In focus groups study, researcher compares data within a group and also between different groups. Since in focus group studies participants influence each other, learn from each other, change their opinions according the things they learn and discussions building on previous comments and points of view, it would be difficult to recognize who is influenced by whom, and what the actual result is. In this study I compared the results of different groups with each other and at the same time tried to discuss them in relation to the earlier quantitative research responses to the same problems, Guttersrud (2008) .

The Analysing process has four steps according to Krueger (1998c): raw data, description, interpretation and recommendation. First step is getting raw data and since data in their raw form do not speak for themselves this step is followed by the other process in analysing continuum. The raw data here were the taped interviews which have been transcribed afterwards. In description phase the researcher provides a brief description of theme followed by literal quotes that illustrate the theme. Interpretation is the third and maybe the most complex step. In this step researcher suggests what the findings mean. The interpretations should be directly linked to raw data that we have from focus groups. These processes in this study have been done by converting the transcriptions into ATLAS.ti and coding them by using the same program.
There were two methods to analyse the data which I could choose between. One option was to analyse each question separately and the other option was to analyse by theme. In this study I thought maybe it would be of use to move data around and placing all responses to a particular theme in one location to compare and contrast responses. With using ATLAS.ti software I retrieved information across several focus groups after the coding whole discussions from all four groups.

2.4.3 Analysing of second part of the focus groups

This part of the focus groups included questions about students' meaning about modelling and about physics teaching and learning more generally?., This part was more like a fully structured focus group study within a moderator asks questions and participants answer to those questions. Analysing of this part was different from the former part. There weren't used any codes here, but by going through the transcriptions from interviews over and over, some interesting findings emerged which are discussed in results and discussion chapter.

2.5 Codes and coding

Coding is the analysis strategy many qualitative researchers employ in order to help them locate key themes, patterns, ideas, and concepts that may exist within their data.
The codes in this study are "pre-determined" codes, (not "inductive-coding") which have been determined from relevant theory and previous works (see below) through discussions with Øystein Guttersrud who developed the problems students solved. These codes got compared to codes from another qualitative study on museum learning theory (Palmyre, 2006) and it was found that the codes used in the present study contained those of Palmyre.

In this study there were used 35 codes which have been written according the theoretical approaches and aims of the study. These 35 codes were organized to 5 "super code" or "family". These five families are based on:

- Family A: Communicative approach
- Family B: Content of interaction
- Family C: Types of talk
- Family D: Types of argument
- Family E: Interchanging between representation forms

2.5.1 Family A: Types of representational approach

Family A has four classes of representational approach listed below. Approaches paying attention to the scientific idea which are correct are termed authoritative, whereas approaches paying attention to not completely correct scientific idea are termed intuitive.
In this family employment of only one representation is denoted single approach, whereas interchanging between different forms of representation are referred to as multiple approaches. These four classes (table 2.1) are inspired of a tool that has been constructed by Mortimer &Scott (2003) for analysing interactions in the science classroom by applying socio cultural theory to classroom practice and the four classes of representational approach constructed by Guttersrud (2008) which are based on the mentioned tool too. Mortimer &Scott (2003) use this approach to provide a perspective on how the teacher works with students to develop ideas in the classroom. In this study this approach is supposed to provide a view of how students discuss or come to a solution in the exercises with focus on mathematical modelling.

Table 2.1:E*xamples of representational approaches based on Guttersrud (2008) and Mortimer& Scott (2003)*

Types of representational approach	**Examples**	**commentary**
authoritative-single representation form	*G. Jeg synes 1ern /A høres riktig ut fordi y er lik ax*	involves a correct scientific idea and just one representation form.
authoritative-multiple representation form	*G.Glass 1 er i hvert fall y=b*	involves a correct scientific idea and interchange between different representation forms
intuitive-single representation form	*J.Hum..ja… det er smeltehastigheten…* *J.Ja…10A* *G.Øker smeltehastigheten ?* *G.Humm…* *J.(…)* *J.Den smelter ikke alt på en gang…det smelter litt og litt…* *G.(…)konstant smelting…*	containes a not correct scientific idea and just one representation form.
Intuitive-multiple Representation form	*du kan ikke gange den opprinnelige vannivået i glasset med noen ting også pluss (…)hva skal vi gjøre da med is bitene for at de to ting nå vi har er isbiter og det er vannivået i glasset …*	containes a not correct scientific idea and interchange between different representation forms

Table 2.2 :*Examples of types of content based on Mortimer & Scott (2003)*

Types of content	Features of content	Examples	Commentary
Empirical-description	• directly observable entities • statements that provides an account of a system in terms of its constituents or displacements of them	*isbiten ligger på toppen der og ..* *J. Det ligger opp på steinen og steinen er litt over vann…* *G. Ja da, akkurat det samme(….)blir det (….)først…det er mye(….)av plassen i glasset* *G. Isen er ikke (….)det komme ikke vann når den smelte* *G. Nettopp …det er …avhengig av…fordi det er uendret i glass 1* *G. Ja ja…* *G. Da (….)* *G. det er alltid …det er konstant, ikke sant? b er konstant…*	Refers to a statement that provides an account of the phenomenon in terms of observable features
Empirical-explanation	• directly observable entities • established relationships between physical phenomena concepts, using some form of model or mechanism to account for a specific phenomenon.	*J .Ja men da er det isbiten som smelter (….)kort tid(….)fort den .strekningen…hva var det (….)* *G. Det vi gjorde …* *J. Hva er strekningen ?:..* *G .Det vi har å forholdes til er det bare at vann standen er høyere før etter at det er ferdig å smelte ,det er vel egentlig ikke noe tid eller akslerasjon*	Refers to description of the phenomenon to establish causal relationships to account for it based on something that can be directly observed.
Theoretical-explanation	• not observable entities in the phenomenon itself. • established relationships between physical phenomena concepts, using some form of model or mechanism to account for a specific phenomenon.	*G. Glass 1 er i hvert fall y=b*	Refers to a description based on theoretical science that isn't observable in the phenomenon
Theoretical-description	• not observable entities in the phenomenon itself. • established relationships between physical phenomena concepts, using some form of model or mechanism to account for a specific phenomenon.	*G. Si at a er 2 og b er 7 hvis x er 1 så blir det jo også…* *J. Hvor er du...?ok…* *G. a er 2 og b er 7…så blir det jo 1-7,nei 2 blir det vel… hvis det hadde vært a 2 og b 7 så blir det jo 2 -7+c og da blir det negativ helt til starten, men etter hvert som x øker …eller …fordi hvis for eksempel blir x er 10 da…10 i annen da er 100,100 ganger 2 minus 7 ganger 10 som er 70 da stiger den jo igjen…* *J. Ja…* *J. Jeg forstår ikke…* *G. men det kan det...jeg mener det var den fordi den synker litt først...*	Goes beyond the phenomenon by drawing on theoretical entities
Theoretical-general	• not observable entities in the phenomenon itself • description or explanation that is independent of any specific context.	*G.Jeg er helt overbevist om at den er 4…* ***Hvorfor?*** *G.Fordi dette er ---(??)og det er identisk andre orden's (….)* *J.Det er faktisk riktig…* *G.Ax i annen pluss bx pluss c ….* *G.Det er alltid(….) hvor vi skal finne ut x …* *J.Nei vi er enig da…*	Goes beyond a description and an explanation in that it is not limited to a particular phenomenon, but express a general property of scientific entities, matter or classes of phenomena

2.5.2 Family B: Types of content

To consider the content of an “argument” is as important as structure when we are investigating student argumentation. According to Mortimer and Scott (2003) , there are three fundamental features of the scientific social language: *description, explanation and generalization*. A further important distinction for these features is that they can be characterized as *empirical* or *theoretical*. Thus, empirical descriptions or explanations are based on directly observable properties, while theoretical descriptions or explanations draw upon entities created through the theoretical discourse of science (Mortimer & Scott, 2003). This family focuses on the substantive content of focus group interactions. With this in mind categories are constructed along two dimensions:

- description-explanation-generalization
- empirical-theoretical

Table 2.2 shows an overview of the categories used for content analysing followed by examples illustrating how the tool is applied in the data analyses.

Table 2.3: *Examples of types of talk and the features of each type, based on Mercer (1995).*

Types of talk	**Features of talk**	**Examples**
Disputational	• Claim • Counterclaim • Challenging question	*Example 1: G.Temperaturen til vannet i glasset, det kan være… G.Det sier ingenting om høyde da G.Nei det kan ikke sikkert G.Hva med tiden fra isen begynte å smelte*
Cumulative	• Repeat • Confirm • Elaborate	*Example 2: G. Glass 1 er i hvert fall y=b G. Ja helt sikkert, det må være (…)er det y=b? G. A høres mest riktig ut fordi at y=b og fordi at y=a ganger x plus en b er det vannstanden før isen begynte å smelte…*
Exploratory	• Explain • Reason • Offer alternative solution • Challenged backed up by evidence/reasoning	*Example 3: isbiten ligger på toppen der og .. J. Det ligger opp på steinen og steinen er litt over vann… G. Ja da, akkurat det samme (…)blir det(…)først…det er mye(…)av plassen i glasset G. Isen er ikke (…)det kommer ikke vann når den smelter G. Nettopp …det er …avhengig av…fordi det er uendret i glass 1 G. Ja ja… G. Da(…) G. det er alltid …det er konstant, ikke sant? b er konstant…*

2.5.3 Family C: The form of students' arguments

The next step in analysing the content of student argumentation was analysing the types of arguments that are used in the group discussion.
This family has a goal to analyse the structure of students' argumentation. The features of Mercer's (1995) categories for small group discussion: disputational, cumulative and exploratory talk were usable to analyze all student utterances in the four group discussions. In analysing process Mercer and his colleagues select sequences of talk from video-recordings of classroom discourse and classify the type of talk dominating the whole sequence. Table 4 provides an overview of characteristics of the types of talk followed by examples of each type talk. It must be noted that single examples of type of talk in Table 3 does not include all the features of each type of talk.

The first example in Table 2.3 is a claim followed by a counterclaim from another student. In Example 2, the fist student presents a claim with reason while the second student repeat, confirm, and elaborate on his (hers) utterances. In Example 3 we can see a classified type of talk as exploratory, since it is not just a counterclaim, but also contains elaborated reasoning with giving an example and a challenge backed by evidence.

2.5.4 Family D: Types of argument

This family involves three different type of content: Physics, Mathematical and everyday

Table 2.4: *Examples of type of argument*

Types of argument	Examples	commentary
Physics argument	*G. Fordi at her triller den med konstant fart bortover bordet så akselererer den fordi at den er i fritt fall …*	Arguments based on physics/natural science
Mathematical argument	*G. A høres mest riktig ut fordi at y=b og fordi at y=a ganger x plus en b er det vannstanden før isen begynte å smelte…*	Arguments based on knowledge about / in mathematical representation
Everyday argument	*G. På Grønland?* *J. Ja… Grønland for eksempel hvor isen ligger på land …*	Arguments based on experience or knowledge from outside the classroom; media (newspaper, TV), leisure hours, etc

2.5.5 Family E: Type of interchanging between representation forms

This family involves the codes that refer to every possible interchange between different representation forms even if they are scientifically correct or incorrect. What the abbreviations used in this family stand for comes below:

Table 2.5 : *Different abbreviations used in this part of study.*

Multi	interchange between two representation forms
Concep	conceptual representation form
Exp	experimental representation form
Grap	graphical representation form
Pic	pictorial representation form
Mat	mathematical representation form
Intui(intuitive)	scientifically incomplete or incorrect
Aut(authoritative)	scientifically correct

Some example statements of interchanging of different representation forms which the student have used during the interviews come here:
Example for multiple-mathematical/experimental-authoritative which means interchanging between mathematical and experimental representation forms. Authoritative is been used when the interchanges is scientifically correct.

> Gutt: *"Glass 1 er I hvert fall y=b"*

Example for multiple- mathematical/conceptual-authoritative which means interchanging between mathematical and conceptual representation forms which is scientifically correct

> Gutt: *"Men hva er tid ganger.. vent da.. jeg bare.. tid ganger et eller annet skal det bli høyde, ikke sant? Du må (...) du skal (...) vann standen.. så b er strekningen, det er 5 cm for at du skal gange a med x også får du strekning"*

Example for multiple- mathematical/ conceptual- intuitive which means an interchanging between mathematical and conceptual which is not scientifically correct or complete:

> *"Gutt1: Smeltehastigheten til isen*
> *Gutt 2: Ja, ikke sant? Det har ingenting med (…) å gjøre.*
> *Gutt3: Hvorfor at det er (…) vannhøyden hvis (…) holde og hvor raskt noen ting smelter.. det .. jo.. det eneste ting jeg kan legge på det er at du har jo svært kort tid, ikke sant?*
> *Gutt2: Ja.*

Gutt1 : mmm
Gutt2: Da har du, men temperature det ser jeg ikke i den.
Gutt1: Nei, ikke jeg heller… Jeg ser ikke noe temperature.
Gutt 2: Men hastighet kan jeg godt forstå eller tid liksom
Gutt 1: Da står det om enten smeltehastigheten til isen eller tiden fra isen begynte å smelte da…"

2.6 Validity and reliability

When we have done a study, we may wonder if we have done a good job. Two concepts can help us throw light on this question. *Validity* and *Reliability* are these two key words.
We can evaluate validity of a study by asking ourselves, are we measuring the same thing we want to measure or not.
Reliability refers to whether a study gives the same in different circumstances or in case the study were performed by another researcher (Robson, 2002). With other words reliability is a matter of control issue. Carelessness, casualness and lack of commitment can guarantee unreliability.
To be able to have a valid measure, the condition is to have a reliable measure. When we have a reliable measure, we can not be sure of having a valid study. To repeat the study as closely as possible and check whether it gives us the main findings of the first study is the practical test of how reliable our study is (Robson, 2002).

Validity and reliability are two conceptions which are more related in quantitative research. In the earlier edition of his book, Robson (1993) uses other terms in relation to qualitative studies as "Credibility, transferability, dependability and confirmability" according to Lincoln and Guba (1985). In his second edition, Robson (2002) again uses "validity" and "reliability" because he means not using the same conceptions in qualitative data as quantitative data may give rise to discussions about invalidity and unreliability of the qualitative studies.

In contrast with quantitative research where the instrument is a proxy for what was really measured, in qualitative research there are no proxies. In qualitative studies the actual words of participants, not the instrument, are used to find out their feelings or observations about the topic of discussion (Krueger, 1998c). Therefore the validity challenge in focus group study is real but lies in another place. One of the threats is that participants will sometimes hold back because of group pressure. To determine the validity in focus group or qualitative studies in general, the researcher must look at the larger context of the study and see the study from the participants' perspective (Krueger, 1998c).

. The focus group study is not intended to generalize beyond the settings of studies; However, Krueger (1998c) suggests the concept of transferability for focus group studies. According to him this concept means that a person who wants to use the results should consider about whether or not the findings can be transferred into another environment. Things which should be done to make this decision are to examine the research methods, the audience, and the context and by evaluating to see if these conditions are sufficiently similar to the new research environment.

2.6.1 Validity and reliability in this study

First of all, getting interview guide, used in focus group studies reviewed by supervisors, who had worked with the PHYS21-project was a way of meeting the reliability and validity demands in this study. To have exactly the same exercises and the same main questions in every focus group discussions strengthens the reliability of this study.

All the interviews which were recorded on tape were transcribed as soon as possible .It was the same person (I) who moderated the interviews and transcribed them. Krueger (1998) means self-transcribing improves analysis with helping the moderator to become intimately connected with the data. Self- transcribing helps to not losing data, something that may happen by doing interviews and transcribing by different persons; thus, self-transcription helps improving the reliability of this study (Bjørkhaug, 2004).

Another point to ensure reliability of this study was using this mark: (…) where it wasn't clear what the participants had said during the interview instead of trying to guess what they say.
Actually to ensure reliability, the interviews should be coded by two researchers independently. In this study there wasn't possibility of doing this process during the whole interviews, but in some part of interviews I got help from Guttersud in the process of going through the transcriptions and reaching agreement about the coding of statements.

According to Krueger (1998c) there are several steps to ensure validity of the results. In this study I have tried to go through these steps. First step was to pilot test the questions to see if they were understood. This testing at the same time helped to see how best we can create an open environment for discussion.

Trying to see the study from the perspective of participants is another step which I tried to improve validity.
The questions which have been asked at the end of each interview were a summary comments and asking them could be a way to ensure that our results are trustworthy and valid.

Since focus group research, including this study, involves only a limited number of people who may not be selected in a random manner, so this promise of generalizability is untenable.

The strength of this study is that it elaborates on and provides in-depth understanding of the quantitative results from Guttersrud's (2008) larger- scale study.

3 Results and discussions

In this chapter I'm going to discuss the results of my interviews with the students in light of quantitative results from Guttersrud's (2008) research and other research in relation to the topics in this study.
In Guttersrud's (2008) research responses to the questions were analyzed quantitatively using the statistics program SPSS. Since there will be consideration to each question separately, the questions will be put in the text to make it easier for readers to have questions accessible.

3.1 Guttersrud's(2008) results in this study

As mentioned before (see 1.1) one of the aims of this study is to compare the data from the interviews with the data from Guttersrud's (2008) study. The goal is to find out if there are any similarities to see if the results from the present study may help us to explain why the students have responded in the way they have done at the quantitative test in Guttersrud's (2008) study. Maybe we can elaborate more on the students reasoning process in the light of his results.
All the tables in this chapter (Results) are the quantitative data from Guttersrud (2008). His test which contained 7 units including the three units used in this study was distributed to a sample of 446 physics students, some of which attending PHYS21 and some attending the "regular" course (see 1.4).

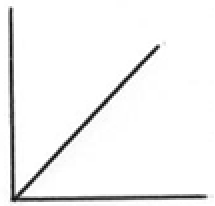
3.2 Results and discussions of "THE CAR" unit

The students were supposed to interchange between conceptual and graphical representation forms in all three items of this unit. As expected the students used the named forms of representation, but the results showed that most of the students were not so good at interchanging between these two forms with correct scientific reasoning. In the line with students' discussions in this study, Leach (1999) observed the difficulties students have during the evaluation of the logical implication of data for knowledge claims.
In this part the answers from the students in the focus groups to each question are going to be discussed.

This question has been divided into three parts. Each part is about a physical conception related to the experiment with a car during its movement across a table and when it is in free fall. In this question the students should evaluate if the given graph can show the car's "displacement" or "acceleration" as a function of time during moving across the table or its "speed" as a function of time when it is in free fall. The students should study the given graph to see if it referred to the car's displacement, acceleration or speed.

THE CAR

Some students carried out an experiment with a toy car. The students pushed the car with **constant speed** across a table. The car then fell from the table edge and down to the floor. Based on the experiment they drew the following graph:



You know these physics formulas: $v = v_0 + at$ and $s = v_0 t + \frac{1}{2}at^2$.

Question 1: THE CAR *U12Q01 concept/graph; evaluate – 0 1 2 3 9*

Decide for each statement if it is correct. Circle "Yes" or "No" for each.

Statement	Is the statement correct?
The graph can show the car's **displacement** as a function of time when the car moves with constant speed across the table. Q01_1	Yes / No
The graph can show the car's **acceleration** as a function of time when the car moves with constant speed across the table. Q01_2	Yes / No
The graph can show the car's **speed** as a function of time when the car is in free fall. Q01_4	Yes / No

u12q01_1

		Frequency	Percent
Valid	1	385	86,3
	2	57	12,8
	missing	4	,9
	Total	446	100,0

Table 3.1: *This table shows frequency of answers to question 1, part 1. 86 % of students stated correctly that the graph shows the car's "displacement" as a function of time (code 1). Almost 13 % did not think the car's displacement was represented by this linear graph (code 2).*

u12q01_2

		Frequency	Percent
Valid	1	113	25,3
	2	328	73,5
	missing	5	1,1
	Total	446	100,0

Table 3.2: *This table shows frequency of answers to question 1, part b. 73.5 % of the students have responded correctly that the graph can not show the car's acceleration as a function of time (code 2). There were 25.3 % who answered wrongly (code 1) that this graph is a representation to the car's "acceleration".*

u12q01_4

		Frequency	Percent
Valid	0	1	,2
	1	233	52,2
	2	204	45,7
	missing	8	1,8
	Total	446	100,0

Table 3.3: *This table shows how many percent of the students have responded correctly or wrongly to the question 1, part 3. There are almost 52% who have given correct answer (code1) which is "the car's "speed" can be shown by the given graph in the question, when the car is in free fall". Almost 45 % of the students have answered incorrectly (code2) that the graph can not show the car's "speed" in free fall period. Code 0 refers to a non acceptable answer.*

The formula in this question which is $s = v_0 t + \frac{1}{2} a t^2$, a mathematical representation of an object moving with constant acceleration, has the same form as the general mathematic expression $f(x)=ax^2+bx$ associated with a parabola with its lowest point at the origin. If the acceleration equals zero the formula reduces to $s = v_0 t$ which has the same form as the general mathematical expression $f(x)= ax$ associated with a straight line through the origin.

Guttersrud (2008) means that to be able to interchange between this mathematical representation and graphical representations of the position of objects moving with constant or zero acceleration which will be a parabola line for the first or a straight line for the later condition, the student is in need for elaborative strategies which means to explore how new physics material relates to what one has learned in mathematics, to extend what is memorized with the earlier knowledge of mathematical functions which is described above.

This item is a vector item (see 1.4.1). In this question, students are supposed to interchange conceptual and graphical representation forms.

If students for instance use the definition of acceleration as the changing of object's velocity with time, it shows that they are using conceptual representation.
If the students refer to the given graph on the question for reasoning their answers then it's the graphical representation form they use. In this problem students are supposed to use "evaluate" category in their reasoning process (see1.4.2). That means they are expected to evaluate scientific claims with respect to empirical data and evidence provided.

Answers

The first focus group gave correct answer to all three parts in this question. They gave correct answer to all three parts, but it doesn't mean that they were good at conceptual and graphical representation forms and translation of them or interchanging them. For instance some of them were not sure about how the graphs of acceleration and speed as a function of time should be look like during the period of free fall of the car.

The second group gave correct answer to part 1 (that the graph was an illustration for the car's displacement) and part 2 (that the graph doesn't show the car's acceleration). The third part wanted the students to see if the given graph could show the car's speed in the period of the car's movement in *free fall*. They gave wrong answer to this part. This is at the same line as Guttersrud's (2008) result. His results showed that in the third part the frequency of wrong answer was highest between the three parts and the frequencies of correct answer and wrong answer had minimum difference in part three. This may show that this part was the most challenging part to the students. Since just in this part the students have been asked about the period of time which the car was in free fall (and not about during the car's moving across the table, like the two first part) maybe the students haven't noticed it and therefore gave wrong answer. Another reason can be that they didn't know how graph of speed, acceleration or maybe displacement can be shown when the car is in free fall and this lack of knowledge led to wrong answer. Discussions about this item in this group showed that they could be able to take conclusion about acceleration from the fact that speed is constant. In the other hand, third part demanded attention to the experiment condition and seemed to be confusing for the students

The third group gave correct answer to all parts. Although they gave correct answer to all parts here, during discussions we found that they didn't know that when speed is constant, the acceleration would be zero. They said that when speed is constant, acceleration will be constant too. We can see that the students here haven't enough knowledge about the mentioned physical law (conceptual). The students didn't use the mathematical expression to find the answer. This may show that they don't know what the components of different equations given in the question 1 mean. If they knew the mathematical expression which relate speed and acceleration, "v=at+v_0", they could find out when speed is constant. At the equation "v=at+v_0" if v is constant it demands v=v_0. This is possible when "at" is zero. Since time can not be zero, then "a" should be zero. With other words learning to simultaneously apply and translate between the various representations, and to refine one's mastery of each representation leads to understanding the physical description of the phenomenon (Angell et al., 2008b).

The forth group gave correct answer to part 1 and 2, but gave incorrect answer to part 3 like the second group. It is obvious from the discussions here that the students didn't take into consideration the car's condition in different parts. Another point was that they weren't able to understand that acceleration would be zero when speed was constant. These statements are evidence to this:

> Gutt1 : *“Den her ikke illustrerer akselerasjon fordi den har konstant fart…”*
> Jente: *”Himm”*
> Gutt2: *”Da kan den ikke akselerere mer enn det”*

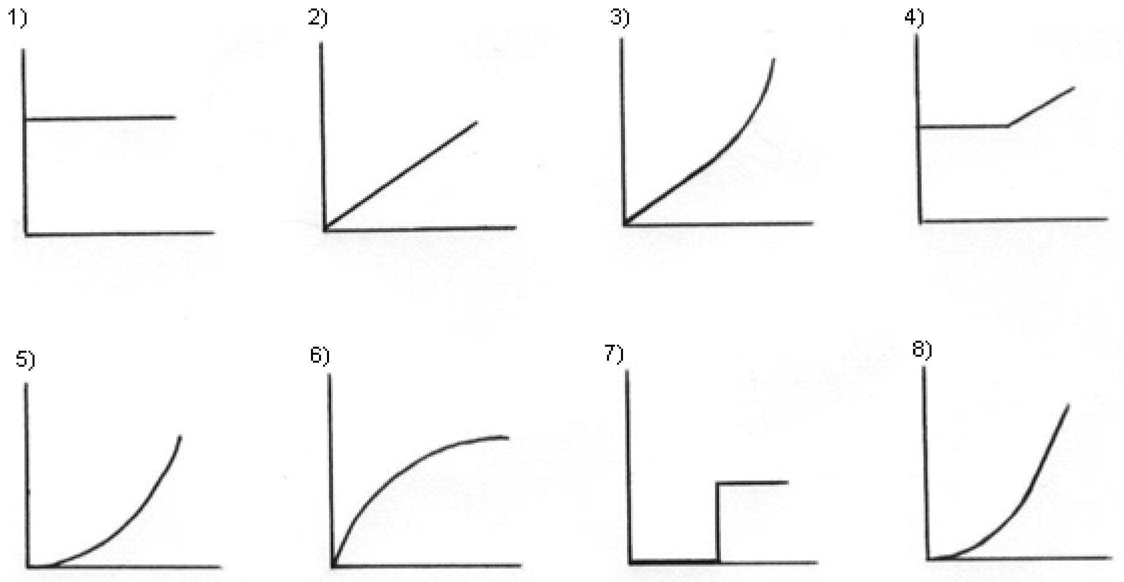
In discussions about this item, the students concluded that the graph of displacement as a function of time when speed was constant was a parabola.

The most popular distractor was related to the third statement which asked if the given graph in the question could show the car’s speed as a function of time when the car was in free fall. One of the reasons for giving wrong answer in this part was that the time period they have been asked in the two first parts of the question was when the car moved across the table (with constant speed), this could make the students confused and they might have had it in their minds during the discussions about the whole three parts of the question and therefore they didn’t notice that the last statement (about speed) was during the car’s free fall.
The other reason may be the lack of ability to interchange or translate between conceptual and graphical representation. From the data from tables 3.1, 3.2 and 3.3 we can see that the distribution of correct and incorrect answers given to the last part which is about the graph of the car’s speed (table 3.3) has minimum difference rather than answers to other two parts. It may show that the last part was difficult to the students.

Question 2: THE CAR

U12Q03 concept/graph; decide – 0 1 2 3 9

Which of the eight graphs below show the toy car's acceleration, speed and displacement respectively as a function of time for the car's entire motion (both when it moved across the table and when it was in free fall)? (Respond by filling in the vacant spaces in the sentences below!)



a) Graph number ___ shows **acceleration** as function of time.

b) Graph number ___ shows **speed** as function of time.

c) Graph number ___ shows **displacement** as function of time.

In this question the students are given 8 graphs. This question is divided to three parts like the former question (1). Students are supposed to find the graphs which illustrate “acceleration”, “speed” and “displacement” as a function of time, among the given graphs.

In the tables below, numbers 1 to 8 stands for the alternative graphs in the question 2. These tables show the frequency of each graph from the students’ answers in the interviews.

Part a) **u12q03_1**

		Frequency	Percent
Valid	0	1	,2
	1	57	12,8
	2	32	7,2
	3	32	7,2
	4	86	19,3
	5	22	4,9
	6	20	4,5
	7	168	37,7
	8	15	3,4
	missing	13	2,9
	Total	446	100,0

Table: 3.4:
In part a (about acceleration) the most given correct answer (7) has frequency 37.7 %.The graph 7 shows that "acceleration" is zero when the car moves across the table and it is constant (9.8m²/s) when the car is in free fall. The most popular distractors are options 4 (19.3 %) and option 1 (12.8 %). In this part, graph 1 means that the acceleration is constant during the whole experiment period and graph 4 means that "acceleration" is constant when the car moves across the table and it increases with constant slope of line when the car is in free fall.

Part b) **u12q03_2**

		Frequency	Percent
Valid	1	51	11,4
	2	61	13,7
	3	82	18,4
	4	176	39,5
	5	22	4,9
	6	18	4,0
	7	6	1,3
	8	16	3,6
	missing	14	3,1
	Total	446	100,0

Tables 3.5 and 3.6:
In part b (about speed) the most given answer is correct answer (4) which has frequency 39.5%. Graph 4 shows that the car has constant speed when it moves across the table and it has increasing speed during free fall. The most popular distractor is alternative 3 which actually shows displacement of the car during its movement.

Part c) **u12q03_3**

		Frequency	Percent
Valid	0	1	,2
	1	39	8,7
	2	135	30,3
	3	133	29,8
	4	16	3,6
	5	30	6,7
	6	34	7,6
	7	8	1,8
	8	29	6,5
	missing	21	4,7
	Total	446	100,0

Table 3.6*:In part c (about displacement) the most given answer is alternative 2 (30.3%) which is incorrect answer and shows just the cars displacement during its movement across the table. Alternative 3 which is correct answer has frequency 29.8 % and is the next most popular answer.*

In this question the interaction between conceptual and graphical representation forms is expected from the students. This question is labelled with "decide" category in relation to reasoning process that means the students are supposed to select from alternative solutions and explanations with respect to empirical data and evidence provided during their argumentations (see 1.4.2)

Answers

The first focus group gave correct answer to all three parts, but they were not sure during the reasoning process. At the part a, which was about acceleration, the students suggested the graphs number "1" and "7". Actually the graph number "1" is a limited part of the graph number "7" which shows the car's acceleration as a function of time when the car is in free fall. The students discussed about the conception of acceleration and how it has changed when the car moved across the table and during free fall. Their conclusion was the graph number "7".

At the part b they were supposed to find the graph which showed speed as a function of time. The discussions showed that they knew how constant speed as a function of time can be shown in a graph. The students also discussed during free fall.

One of them said that speed would increase during free fall and suggested the graph number "4" which was the correct alternative. Another student claimed that the line of graph which refers to free fall should be downwards. It shows a misconception and shows that the student hasn't understood the meaning of directions in the graphs. The thought behind this answer maybe was: "since the car is in free fall toward the ground then, the direction of the graph should be the same (to down)". After these discussions one student suggested the graph number "3", which shows speed increasing the whole time (incorrect answer). Discussions showed that the students knew graph which showed the car's speed when it moved across the table was a straight line. Results also indicated that it was difficult for the students to choose a graph which showed the car's speed during free fall.

At part c (about displacement) they suggested the graphs number "5" and "8". These two graphs were the most close to the correct answer (the graph number "3"). The graph number 5 shows that the car begins to after a small time interval and that displacement increases as a function of time. The graph number "8" differs from the graph number "5" in that the former graph is straight line at the second phase. Another student suggested the graph "2" as a correct answer. The graph "2" is straight line and shows displacement when the car has constant speed moving across the table. This suggestion started a discussion again and one of the students mentioned the fact that in choosing the right graph they should take into consideration the whole conditions during the moving of the car and not just a part of it.

> Jente: *"tiden… og i forhold til bevegelsen… så jeg tror ikke den er "2"ern. for da må det være en forskjell på mens den går her"*

At last they agreed about the graph number "3" which is straight line at the beginning and parabola in the second phase. After this conclusion one of the students noticed that they have chosen the same graph for "speed" and "displacement" at the same time. She meant that it couldn't be right. Then they discussed more and found out that it is the graph "4" which shows speed as a function of time. The graph "4" shows constant speed in the first period, during the car's movement across the table and increasing speed with constant slope of line during the car's free fall.

<u>The second group</u> gave correct answer to all three parts of this question. In this group there wasn't so long discussion as in the first group. The reason may be the students in this group had more knowledge about graphs and conceptions rather that the participant in the other group. The correct answer in the last part (about displacement) was the graph number "3". One student in this group suggested graph "2" which shows increasing displacement whole time with constant slope of line. The first group had also chosen the graph number "2" first. The obvious difference here was that other students didn't accept the answer without arguing. One of the students opened the former student's eyes to the condition given in the question:

> Gutt1: *"Strekningen er vel "2"ern"*
> Jente1: *"Nei"*
> Jente2: *"Nei …"3""*
> Gutt1: *"Oh ja. For at den er både mens den triller og mens den faller?... Riktig riktig… da satser vi på 3 da?*
> Gutt2: *"Ja"*

Here we can see the advantage of group working.

<u>The third group</u> had a good discussion about this question and they gave correct answers to all parts. Discussion in part a, was in a way that they completed each other's reasoning and at the end they gave a correct answer as a result of a good discussion. Their statements showed that they often were able to translate and interchange between conceptual and graphical representations as was expected from them to do during the discussion. In their discussions about the speed there was a sequence which can show us how students can learn from each other during discussion. One student gave an incorrect answer, graph "1" (is a straight line) to the last part (the graph which is supposed to illustrate speed as function of time). The other

students argued with him until they agreed about the correct alternative which was graph “4” (is combination of two straight- line segments)

> Jente1: *“ Og 2b er “1””*
> Gutt1: *“ Farten øker på slutten”*
> Gutt 2: *”Farten øker på slutten”*
> Jente2: *”Ja ja, det gjør den”*
> Jente1: *”Ja men da ok…”*
> Jente 2: *”Den faller … da er den 4”*

In part c they were supposed to discuss and find out which graph showed displacement as a function of time. They had good reasoning in this part. As soon as a student began to be in doubt about the answer and suggested another alternatives the others tried to give good reason to prove why their answer was correct.

> Gutt: *“Hvis det er nummer “3”, kan det være nummer “5” også.”*
> Jente: *”Nei. Fordi at den er ikke konstant først…linje er (…) du ser at den starter helt rett … og når vi kjører…”*
> Gutt: *”Nummer ”5” starter rett også .. men det er også…”*
> Jente: *”Du ser at den er hevet ut her , at den er ekstra (…). Den nummer ”3” … jeg er sikker på det… men det kan være feil…”*

The forth group didn’t discuss as much as the third group, but they had after all correct answers. They had also a short conversation about why they thought their answers were correct.

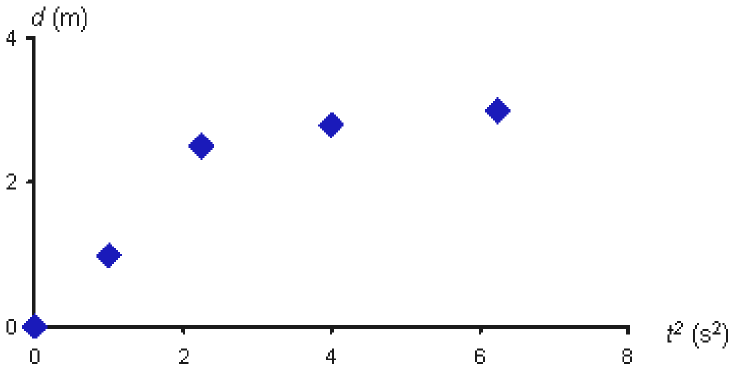
As shown above all the focus groups had answered correct to all parts of this question. Guttersrud (2008) hadn’t the same results. From the table 3.6, it can be shown that at the third part the frequency of most popular distractor was higher than the frequency of correctly answer. The low frequency of the correct answer may show that this question was a challenge for the students in his study.

The fact that in present study all groups answered correctly to all three parts of this question doesn’t mean that the students have had good and scientifically correct reasoning process to get these answers or that they have understood all points in relation to the question, as shown during the discussions between the students. The reason may lie in the form of this item. This question is different from question 1 in some ways. The first one is that in question 2 students have more alternatives to choose between rather than in question 1. In question 1 there was shown one graph and different concepts to find relationships between. The second difference is that in this question it is the same condition during the whole question and the students aren’t under the necessity of adapting to the different conditions, thus in this question there is lower chance for the students to be confused.

The students attached a rope to the car and tried to pull it with constant acceleration across the floor. The students measured displacement and time, and they plotted displacement as a function of the time squared.

The students knew that displacement may be written as $s = ½ at^2$ when the initial speed is zero.

d(m)	t(s)	t^2(s^2)
0	0	0
1,0	1,0	1,00
2,5	1,5	2,25
2,8	2,0	4,00
3,0	2,5	6,25



Question 3: THE CAR

U12Q05 concept/graph; conclude and com.
– 01 02 03 04 05 06 07 08 11 12 19 21 22 99

May the students conclude that the acceleration was constant? Explain your answer.

....

....

In this question the students are supposed to interchange between conceptual and graphic representation forms. In relation to reasoning process it is expected that the students use the "conclude and communicate" option which means to draw and communicate valid science-based conclusions anchored in empirical data and evidence provided. The students are also supposed to make and communicate scientific explanations to justify solutions in this problem.

u12q05

		Frequency	Percent
Valid	1	29	6,5
	2	11	2,5
	3	7	1,6
	4	11	2,5
	5	10	2,2
	6	48	10,8
	7	41	9,2
	8	51	11,4
	11	11	2,5
	12	6	1,3
	19	14	3,1
	21	82	18,4
	22	31	7,0
	missing	94	21,1
	Total	446	100,0

Table 3.7*: this tables shows frequencies of the coded answers coded according to Guttersrud's (2008) coding system(see appendix 2)). Each code refers to a response category which is constructed by him. From this table we get information which shows in this study the most frequent category was "missing". The most popular correct answer was code 21 that refers to acceleration "not" being constant on the grounds that the dots did not lie along a straight line or equivalent (for more details see appendix 2). The most frequent alternative answer was code 8 which refers to answers not including scientific reasoning in the process of explaining of why acceleration is "not" constant, e.g. "No, then they would have another curve" or "No, because then the graph would have looked different" (for more details see appendix 2.).*

Answers

In the first focus group they gave correct answer to this question that asked may the students conclude that the acceleration was constant from the given data. By calculating the formula by setting different numbers in the formula and not getting the same results for acceleration the students concluded that the acceleration was not constant. The method of setting numbers in the formula and calculating is actually a quantitative method. According to Guttersrud's (2008) scoring system this kind of answer gets code 22, which refers to acceleration not being constant on the grounds that the dots not lie along a straight line or equivalent (see appendix 2 for more details). An answer coded 22 gets full credit. The students actually had interchanging between mathematical and graphical and conceptual representation forms during their discussions.

The second group didn't give the correct answer and they didn't have any good reasoning either. They concluded that acceleration was constant which was not correct. According to Guttersrud's (2008) scoring system, they get no credit or specifically code 08 which refer to acceleration being constant. The students first tried to use quantitative method by setting number in the given formula to see how acceleration changes, but they couldn't get any conclusion about acceleration from this process. They tried then to translate what the given graph meant, but they were not good at qualitative method either.

The third group was not sure about the correct answer and they gave a partially correct answer which coded 12, which refers to acceleration not being constant on the grounds that the graph is not parabolic or exponential (see appendix 2 for more details) according to Guttersrud's (2008) system. It is interesting to see how this group discussed. This group first tried to find out how they can change the given formula which was based on displacement to get a formula based on acceleration. It was a good idea, but they couldn't execute the process. Then they tried to discuss what the graph showed to them and they were not good at translating a graphical form either. They came back to first method again and this time put numbers in the given formula, but didn't get a logical answer to how acceleration changes from the results they had got from putting numbers in displacement formula. With more discussion we found out that there were some students who hadn't understood what actually the symbols beside axes meant. D (m) which means "distance" in meter was the symbol for axis "y" and t^2 (s^2) means "time" squared in second squared was the symbol for axis "x". The students had a mistake that D (m) is multiplication of two unities and t^2 (s^2) is time multiplied by displacement. During the discussion they found out that they had misunderstood the meaning of these symbols.

Jente1: *"Nei, det er jo ikke tiden, det står tid i annen ja så ganger strekningen i annen?"*
Gutt: *"Det har jo .. den der er jo tid i annen ganger (...) "*
Jente2: *"Sekund i annen .. tid i annen og sekund i annen."*
Gutt: *"Aha"*
Jente1: *"Strekning i meter ikke sant?"*
Gutt: *"Selvfølgelig… jeg trodde at … da skjønner jeg godt. Da skjønner jeg… Da blir det litt lettere"*

Along similar lines, the results of FUN study showed that students expressed that it was difficult to keep the various expressions and formulas apart, especially since some of the symbols appear in different contexts (Angell et al., 2004).

The forth group gave correct answer to this question. After reading of the question one of the students stated facts and reviews from the question. He said, actually if acceleration was constant then the graph should be shown in straight line and concluded that acceleration couldn't be constant. The other participants in the group didn't discuss about his answer and just accepted what he said. Although they hadn't enough reasoning their answer got full credit, according to Guttersrud's (2008) code system, code 21. Code 21 refers to the answers which say acceleration is not constant on the grounds that the graph is not parabolic or exponential (see appendix 2 for more details).

There can be two reasons for having short discussion in the latest group, the first one is that other students in the group who didn't argue with the one who gave answer, didn't have any idea about what had been asked and therefore had nothing to say. The second reason can be that the other students in group had the same meaning as the one who gave answer and they didn't see any reason to discuss.

The data from Guttersrud's (2008) study showed that there were almost 21% who didn't answer this question. This was the highest frequency in this question and it can be normal, because this question is an open- question and some students don't care about answering this kind of questions. In this study all the groups answered this question. The reason may be that in this study we had focus group study and there was a moderator who was following the students' answering process. Code 21 which refers to the answers saying acceleration is not constant on the grounds that the dots (in the given graph) don't lie along a straight line or equivalent (see appendix 2 for more details), was the most given complete answer in Guttersrud's (2008) data.

In this study there wasn't any group that responded with an answer coded 21. The first group's answer coded 22 which refer to answers saying acceleration is not constant on the grounds that the increase in speed is not constant (for more details about coding see appendix 2). This kind of answer in Guttersrud's (2008) data had frequency 7%. The second group's answer was coded 08 which refer to answers with not a specific reasoning. The code08 had frequency 11.4 % in Guttersrud's study. The third and forth groups' answers coded 12 which refers to "acceleration not being constant on the grounds that the graph is not parabolic or exponential (for more details see appendix 2) Answers that are coded 12 are partial correct. This code in Guttersrud's (2008) data has just 1.3 % frequency.

In this question we see that results from Guttersrud's (2008) study and this study are not like each other and this may show that an individual, written test is different from a group discussion situation and that group working here is often more effective than individual problem solving from the named written test.

The student didn't use every-day arguments in relation to THE CAR unit. It might be students who don't see any relationship between mechanics and every day life. In this relation results in the study FUN showed that students see the issues like relativity, quantum physics and astrophysics as more relevant to their everyday lives than acceleration, friction, and current. It is concluded in the FUN study with the statement below:

"This may be related to the growing alienation from everyday technology: Whereas some decades ago, it was natural for a person trained in physics to repair cars and radios, today most technological products are built from "black boxes" and microchips and cannot be understood even by persons trained in physics" (Angell et al., 2004,p:691).

3.3 Results and discussions of “SEA LEVEL” unit

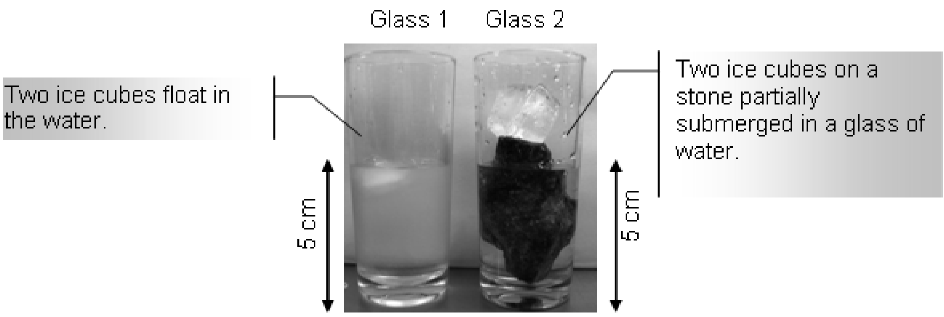
SEA LEVEL

Some students wanted to study how the melting of ice around The South Pole and in the areas around The North Pole influences the sea level.

The students filled a glass (glass 1) with water. When they put two ice cubes into the glass, the water level was 5 cm. The students put a stone into an identical glass (glass 2). They put two ice cubes on top of the stone and filled the glass with water until the water level was 5 cm there as well.

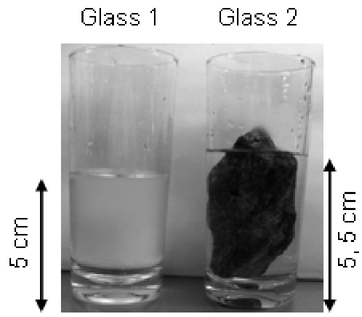
At the North Pole there is no land under the ice, but at The South Pole there is. The stone represents these territories. Glass 1 thus represents The North Pole, while glass 2 represents The South Pole.

BEFORE MELTING



The picture below was taken after the ice cubes had melted:

AFTER MELTING



Question 9: SEA LEVEL *U14Q01 math/exper; Identify/apply – 0 1 9*

Assume that the ice is melting with a constant rate. Which mathematical expression describes the water level (y) in glass 1 and glass 2 while the ice melts?

A Glass 1: $y = b$, glass 2: $y = ax + b$

B Glass 1: $y = ax + b$, glass 2: $y = b$

C Glass 1: $y = b$, glass 2: $y = ax$

D Glass 1: $y = ax$, glass 2: $y = b$

As it is mentioned before about the importance of the argumentation we can also say that practicing of argument empower students with the ability to critically examine the scientific claims in their every day lives (Driver et al., 1998). This unit can be an example to such an examination which can be related to global warming that is a part of today students' every day life.

u14q01

		Frequency	Percent
Valid	0	4	,9
	1	301	67,5
	2	26	5,8
	3	68	15,2
	4	14	3,1
	missing	33	7,4
	Total	446	100,0

Table 3.8: *In this table each numbers 1, 2, 3and 4 stands for answer alternatives A, B, C and D in the question.*
This table show that answer alternative "A", which includes the mathematic expressions "y=b" for glass 1 and "y=ax+b" for glass 2 has the most frequency (67.5 %). The answer "C", "y=b" for glass 1 and "y= ax" for glass 2, had frequency of 15.2 %but there is a big distance between these two. The reason that the students had chose alternative "C" may be that they have misunderstood about the conception of component "b" in the expressions.

In this item the physical interpretation of the constant "b" is the initial water level in the glasses. The constant "a" is interpreted as the ice's melting speed. The focus of this experiment is to show that ice floating in water will not contribute to the expected rise in sea level due to global warming.

In this question the students are supposed to interchange between mathematical and experimental representation forms. If the students use the mathematical equations in relation to the experiment and are able to translate between these two forms, we can say this question has achieved its goal. The reasoning process expected in this question is "Identify/apply" which means the students are supposed to identify shared properties of physics formulas and to apply knowledge and general mathematical expressions to describe physical phenomena and to plot experimental data (see 1.4.2).

Answers

The question here is to choose correct mathematical expressions which describe the water level in both glass 1 and 2. The important point here is that students should have understood what each component in mathematical expression means and which one is variable and which one is constant. At the other hand the students should be able to connect these mathematical expressions to the described experiment (interchanging between mathematical and graphical representation forms). According to the experiment and the fact that in glass 2, constant "b" as the initial water level should be taken into consideration, the correct answer is alternative "A" (glass 1: y=b, glass 2: y=ax+b). According to Guttersrud (2008) the most popular distractor is alternative "C" (glass1: y=b, glass 2: y=ax) which doesn't have constant "b" in the mathematical expression related to glass 2 .The expression "y=ax" describes the change in water level and not the actual water level in the glasses which is been asked about.

Three groups gave the correct answer to this question. The last group had doubt between option "A" (glass 1: y=b, glass 2: y=ax+b) and "C" (glass1: y=b, glass 2: y=ax).

In the first group they talked first about the glass "1" and they were sure that it is the expression "y=b" which describes the water level there. About glass "2", one student said that y= ax+ b is the correct alternative, and he said that "b" was the original water level in the glass"2". According to Guttersrud (2008), not knowing what "b" referred to, were the most common reasons for distractsor in his study. The other student began an argumentation not with purpose of counterclaim. He was looking for more reasons that could help him to understand why alternative "A" (glass 1: y=b, glass 2: y=ax+b) was correct answer.

The second group were in doubt between alternative "A" (glass 1: y=b, glass 2: y=ax+b) and "C" (glass1: y=b, glass 2: y=ax) at the beginning. The main reason for choosing alternative "C" as a possible correct answer was that some of the students in the group hadn't understood what "b" referred to. They didn't know that "b" was a constant, not a variable. During the discussion one student came with comments about "b" and this led the group to the correct answer.

> Jente1: *"Glass "2", det blir litt større, det blir plusset på litt… det blir 0.5 større… så er det kanskje ax pluss b da?"*
> Jente2: *"Nei?!"*
> Gutt1: *" Hva skulle "b" der?"*
> Jente 1: *"Jo… fordi det er en økning…"*
> Jente2: *"(...) starter på en vist punkt…"*
> Gutt1: *"Men ax pluss b (...) den der ja…"*
> Gutt2: *"Men det er jo egentlig noe helt annet. Det er det for så vidt."*
> Gutt 1:*"Da er det ax+b fordi den starter et sted. Den starter ikke på null så jeg vil si det er "A".*
> Jente: *"Ja"*

The third group had no problem with choosing the expression that described the water level in the glass "1", but they were not sure about the correct answer for glass "2" at the beginning of the discussion. They were also in doubt between alternatives “A” (glass 1: y=b, glass 2: y=ax+b) and “C” (glass1: y=b, glass 2: y=ax), like the former group. After discussion in the group it was clear to all participants that “b” was the original water level which was constant and that “b” should be taken into consideration in description of water level(y) in glass 2 and the group agreed about alternative “A” which shows “y=b” for glass 1 and “y=ax+b” for glass 2.

The forth group first mentioned the two alternatives “A” and “C”, like the other groups. This group had also a short discussion and they showed that they have understood what the expression of “b” meant and chose the correct answer which is alternative “A”.

According to discussions above, we saw that if the students didn’t have knowledge or haven’t learnt about constant ‘b’ which was the original water level in the glass ‘2’it was a bigger possibility for them to choose the wrong alternative ‘C’(glass1: y=b, glass 2: y=ax). In Guttersrud’s data there were 67.5 % who chose the right answer, which was alternative ‘A’ (glass 1: y=b, glass 2: y=ax+b). In this study all the groups picked up the correct answer at the end of their discussions. During their argumentation the students used interchanging between the expected representation forms and they used the expected reasoning process which was classified as “identify/apply” according to Guttersrud (2008) (see 1.4.2). This process involved identifying shared properties of physics formulas and applying knowledge and general mathematical expressions to explain physical phenomena.

Question 10: SEA LEVEL *U14Q02 concept.math; decide – 0 1 9*

What does the x in the expressions in the previous question refers to?

A The melting speed of the ice
B The original water level in the glass
C The temperature of the water in the glass
D The time from the ice began to melt

u14q02

		Frequency	Percent
Valid	0	1	,2
	1	115	25,8
	2	103	23,1
	3	25	5,6
	4	167	37,4
	missing	35	7,8
	Total	446	100,0

Table 3.9*: The numbers from 1 to 4 is for answer alternatives A, B, C and D. This result table shows that the most popular answer was the correct answer D which shows the “x” in the expressions from the previous question refers to “the time from the ice began to melt”. The two popular distractors are A which shows the “x” refers to “the melting speed of the ice” and B that shows the “x” refers to “the original water level in the glass”. The somewhat even distribution may indicate that there weren’t many students who were sure about which one was the correct answer.*

This question is a “multiple-choice” question type. In this question students are supposed to use interchanging between conceptual and mathematical representation forms, for example to explain what “x” is used in a mathematical equation means.

In this question the expected reasoning process is recognized as “decide” which means that students select from alternative solutions and give explanations with respect to empirical data and evidence provided (see1.4.2).

The first group gave correct answer, but they didn’t have correct scientific argumentation for their answer. The main reason was that they didn’t know what each of the characters in the mathematical expressions symbolized. They suggested each of the alternatives in the group discussion to see if it was the correct answer. The alternative that they thought could be the least logical was alternative “C” which was about the temperature of the water in the glass. Their interview session showed that they were good at argumentation, but they hadn’t had enough scientifically correctly information to base their reasoning on and at the end they guessed their answer. The problem was that they considered “b” as a variable and they weren’t able to interpret “b” as initial water level.

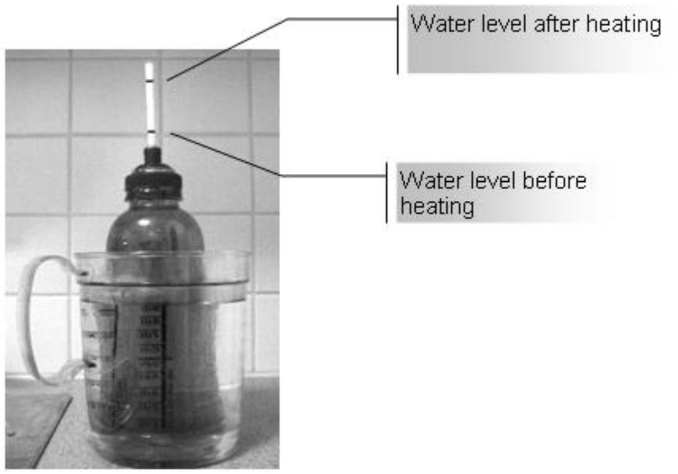
The second group gave wrong answer to this question. They chose alternative “A” which was that “x” referred to the melting speed of the ice. They didn’t accept alternative “B” (the original water level in the glass) because they were sure about what the original water level in the glass was (“b”). They didn’t even discuss about two other alternatives, “C” and “D” which the former was about temperature of the water in the glass and the later was about the time from the ice began to melt.

In the third group a student suggested the correct answer and the others agreed with her, they didn’t have good reasons for their choice

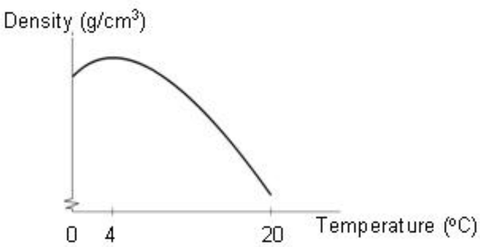
In the forth group, the students didn’t argue much. One of them suggested the correct alternative (D) which showed “x” referred to the time from the ice began to melt and each of the other participants gave a reason to prove that alternative “A” and “B” were not related in this question. They didn’t talk about the third alternative(C) which was about temperature. This shows that maybe they didn’t have enough information to talk about this topic or they just didn’t care about that alternative.

As shown above three of four groups gave correct answer to this question. They didn’t have good reasoning for their answers. This may show that they just have guessed the answers. The main problem was lack of knowledge about the meaning of different parts in the given mathematical expressions. In the discussions in the groups the expected reasoning process was of ‘decide’ type which meant students should select from their alternative solutions and explain with respect to empirical data and evidence provided (see 1.4.2). For example in the second group they didn’t follow this process completely. The evidence for this was that they didn’t even talk about two of alternatives and didn’t explain their answers. According to Guttersrud’s (2008) data the frequent answer in his study to this item was alternative “D” with 37.5 % and the most popular wrong answer was alternative ‘A’, the melting speed of the ice, (26 %). In this study the only wrong answer was alternative “A”, the same as in Guttersrud’s (2008) data.

The students filled a bottle with cold water (0 ^{0}C). They made a hole in the cap and attached a thin straw (see the photography). They placed the bottle in a container with water (20 ^{0}C). The lower line on the straw shows the water level before the bottle was placed into the warm water, while the upper line shows the water level in the straw after the water in the bottle and container had reached the same temperature.



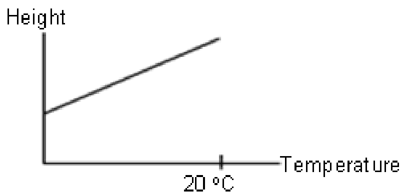
The figure below shows the density of water as a function of temperature:



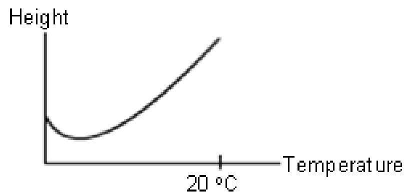
Question 11: SEA LEVEL *U14Q03graph/exper; decide – 0 1 9*

Which of the graphs below shows the height of the water in the straw as a function of the temperature of the water in the bottle?

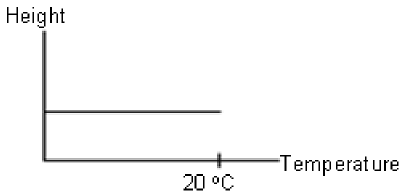
I)



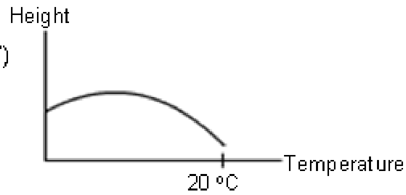
II)



III)



IV)



A Graph number I
B Graph number II
C Graph number III
D Graph number IV

u14q03

		Frequency	Percent
Valid	1	142	31,8
	2	233	52,2
	3	12	2,7
	4	30	6,7
	missing	29	6,5
	Total	446	100,0

Table 3.10*: In this table also the numbers refer to the four answer options, A, B, C and D. The most frequent answer is "B". The most popular incorrect answer is "A".*

This question is a "multiple-choice" question type. Here students were supposed to relate the given graph to the given experiment to find out which graph showed the height of the water in the straw as a function of the temperature of the water in the bottle. The correct answer in this question is, as mentioned before, alternative "B" which shows that the height of the water as a function of temperature of water first goes down and then up when temperature goes up. This is because the water has the highest density in 4 ^{0}C and its density decreases with increasing of temperature. As shown in table… the most popular incorrect answer is alternative "A" which shows that the height of the water just increases in linear form as a function of temperature .The reason that students have chosen the incorrect answer "A" or graph "1" as representation for the height of water might be that they haven't take into consideration the fact about how the density of water changes in 4 degrees.
In this question which is supposed to be an interchanging between graphical and experimental representation forms the students are expected to use the "decide" category which is described above, during their argumentations (see1.4.2)

Answers

The first focus group didn't give correct answer to this question about the height of the water in the straw as a function of the temperature of the water in the bottle. They knew that in general situation the water level goes up when temperature goes up. Based on this point they omitted alternative "D" which didn't show this fact. They chose alternative "A" which satisfied their reasoning. There is another fact that during increasing of temperature the density of water will gain its highest value at 4 degree and after that temperature the density begins to decrease and that lead to increasing of the height of the water when temperature continue to be more after 4 degree. In this group the problem was that the students weren't aware of this fact and therefore it was difficult for them to find the right graph.

The second group gave correct answer to this question. They had a short discussion. One student said that she had thought about alternative "2" (the correct alternative) and used scientifically correct answer by mentioning the fact about 4 degrees which has been discussed above. Discussions showed that the students had different meaning, but at last they agreed about the correct answer.

The third group gave correct answer. One of the students suggested alternative “2” which was the correct answer. There were two other students which complained about not understanding what the given graphs mean and one of them didn’t know what was going on in relation to the question. The first student tried to explain what the question was about and talked about 4 degree’s importance in the density of the water. This is another example which indicates that it is possible to learn during group discussion. It also shows the positive side of group work. If a student works alone on a question and doesn’t understand it, he/she won’t be able to answer the question. But in the discussion of the third group we saw that if it happens in a group there is a possibility of being explained about the question from other participants in the group.

> Gutt1: *“ Neste.. det må være “B” også graf ”2”.”*
> Jente: *”ja.. husker ikke”*
> Gutt 2*:” Kan nesten ikke”*
> Jente: *”For å være ærlig forstår jeg ikke hva sto der”*
> Gutt1: *”Det er tettheten. Jo større tettheten jo lavere går den.”*
> Jente: *”Hva var det som skjedde? Jeg fikk ikke med meg.”*
> Gutt1: *”Du .. Vi kuler en flaske vann til null grader. Da er den her sånn. Det er nesten (...)”*

And the discussion continues until the girl understood what was going on.

The forth group gave the correct answer, but had short discussion. They began with suggesting graphs “1” which is increasing linearly or “2” which shows decreasing of the water level at the beginning and then increasing of that as a function of temperature. This shows that they have understood the height of water increases in the process of melting of ice. When they took into consideration the fact about the density in 4 degrees, they chose the correct answer which was alternative: B” and showed the decrease of water height before 4 degrees and increasing of that after 4 degrees.

Reviewing discussions in focus groups shows that most of the students could relate their data from experience to the given graphs to find out the right one. The results showed that they followed the “decide” reasoning process which was expected of them to do, during their discussions.

Three of four groups answered right to the question. According to the data from Guttersrud (2008) there were 52.2% which had chosen the right alternative in his study. The most common distractor in his study was alternative “A” (graph number I) with frequency of 31.8 %.
First group’s answer which was wrong was alternative “A” too. The main reason that led to wrong answer in that group was that its participants didn’t know that water’s density is the highest at 4 degree. It is possible that the students who answered wrong in Guttersrud’s (2008) study also didn’t notice the fact about the water in 4 degree.

Question 12: SEA LEVEL *U14Q04 math/graph; Identify/apply – 0 1 9*

In the frame below there are some mathematical expressions numbered 1-12.

Note: the constants a, b and c are positive and greater than zero:

1) $y = -ax^2+bx-c$ 2) $y = -ax^2+bx+c$ 3) $y = ax^2-bx+c$ 4) $y = ax^2+bx+c$
5) $y = ax^2+bx$ 6) $y = -ax^2+bx$ 7) $y = -ax^2-bx$ 8) $y = x^2+x$
9) $y = ax+b$ 10) $y = ax$ 11) $y = x$ 12) $y = a$

Which expressions express the graphs above best?

a) Graph **I** is best expressed by expression no.________.

b) Graph **II** is best expressed by expression no.________.

c) Graph **III** is best expressed by expression no.________.

d) Graph **IV** is best expressed by expression no.________.

In this question which is a combination of four multiple choice parts, students are supposed to chose the expression which expresses each of the graphs showed in the previous question (question 11) I, II, III and IV best. In each part student are going to choose one mathematical expression that represents the given graph.

Here the goal is that students use mathematical representation form interchanging with graphical form by choosing a mathematical expression that expresses the graph best. The process which the students are supposed to choose during the reasoning is detected as “Identify/apply” which is described before in 1.4.2.

Part a)

u14q04_1

		Frequency	Percent
Valid	1	3	,7
	2	1	,2
	3	1	,2
	4	3	,7
	5	3	,7
	6	4	,9
	7	1	,2
	9	335	75,1
	10	45	10,1
	11	3	,7
	12	2	,4
	missing	45	10,1
	Total	446	100,0

Table 3.11*: In this table numbers from 1 to 12 refer to the twelve mathematical expressions which are given as answer alternatives to question the straight-line graph, no I. The most given response is the correct answer 9 which is "y=ax+b" and is a mathematical representation form for a linear graph with a constant positive slope of line and a start point which is positive and not zero. The most popular distractor is the expression number 10 which refers to almost the same graph as before but begins at zero.*

Answers

The first group gave a correct answer to part one. There was first a student which suggested expression "6" ($y=-ax^2+bx$) which is the second order expression. The other student suggested expression "9" (y=ax+b), which was the correct answer and others agreed with him. They didn't discuss what the components of the suggested expressions meant and how those influenced the graphs.

The second group gave correct answer to this part too. It seemed to be obvious to the students that the answer was the expression "ax+b" and therefore there wasn't any discussion about that.

In the third group also the students were sure about the answer of this part and they answered correctly.

The forth group gave the same answer without any discussion.

We see that all four groups gave correct answer to this question and almost all of the students were sure about the answer and it seemed to be easy for them. According to Guttersrud's (2008) data 75% of the students in his study have given correct answer. It may show that this part is simple to most of the students.

Part b)

u14q04_2

		Frequency	Percent
Valid	0	4	,9
	1	11	2,5
	2	62	13,9
	3	84	18,8
	4	129	28,9
	5	24	5,4
	6	27	6,1
	7	8	1,8
	8	15	3,4
	9	6	1,3
	10	5	1,1
	11	1	,2
	missing	70	15,7
	Total	446	100,0

***Table 3.12**: This table is a result for choosing of a mathematical representation form which expresses the graph II best. Like the result table for question 11, numbers 1 to 12 stand for the twelve mathematical expressions which are given in the question. The most frequent expression for graph II is the wrong answer 4 "$y=ax^2+bx+c$" which is a mathematical form which refers to second order. Frequency for the correct answer, expression 3 "$y=ax^2-bx+c$", is 18.8 % . The difference between these two expressions, 4 and 3 is in the sign of "b". It may show that there are many students who don't know actually what "b" means.*

Answers

The first group chose a second order expression, but that wasn't expression which expressed the given graph ("2"). Choosing the second order expression shows that they knew the difference between the first order and the second order expressions. The answer they gave was the alternative "4" ($y=ax^2+bx+c$) which is different from the correct expression "3" ($y=ax^2-bx+c$) in the sign of "b". This shows that maybe the students haven't understood what "b" refers to in an expression.

The second group chose the incorrect alternative "4"($y=ax^2+bx+c$) too. This means that they haven't understood what "b" means either.

The third group gave a correct answer, but the discussion in the group showed that they had no idea about what "a", "b" and "c" meant. The reason can according to Angell et al. (2007) be that it is easy for the students to identify the 'slope' and the 'interception' in linear equations when being in a mathematical mode, but found it difficult to identify the roles of the corresponding constants in a physics formula. First of all they are in doubt between alternatives with different sign for "a" ("2" and "3") and they couldn't get a scientifically reasoned answer during the argumentation. Then they tried between options "3" ($y=ax^2-bx+c$) and "4" ($y=ax^2+bx+c$) which had different sign for "b". Their reasoning here wasn't scientifically correct either. They tried afterwards use quantitative method with putting numbers for "a" and "b" and "c", but since they didn't know what those characters referred to, the discussion led to more confusing for all of the participants in the group. They even tried to choose alternative “5” ($y=ax^2+bx$) which didn’t have the last part “c”. At the end of the discussion they guessed that alternative “3” ($y=ax^2-bx+c$) could be the correct answer.

The forth group began with talking about the second order expressions. One of the students asked what sign “a” should have in relation to the graph 2. The others weren’t so sure about that. Then they just started another discussion about what “c” meant. They had enough information about “c”. They knew that in the graph 2 the sign of “c” should be positive because the graph cuts the axis “y” in the positive part. They were still not sure about the meaning of “a” and “b” and they thought that “a” should have positive sign, without giving a reason and “b” should have negative sign, because the graph goes down first that wasn’t a correct reasoning about the sign of “b”. They didn’t give a concrete answer, but the most suitable expression according to their reasoning was “3” ($y=ax^2-bx+c$), which was correct answer.

From the reasoning that the forth group had, we can conclude they could chose alternative “3”, although they didn’t say it directly. According to Guttersrud’s (2008) data the most frequent answer in his study was alternative “4” with 28 % and the correct answer, “3”, had a frequency of 18%. We can conclude from his data and the data in this study that this part was difficult to most of the students. During the discussion the students had in this study, it has been shown that they knew the difference between graphs based on first order and second order expressions. The challenge for them was the meaning of different characters used as component in a second order expression and what their signs meant. Since the most popular distractor was alternative “4”, it may show that sign of “b” or the conception of “b” itself could have been the most confusing part for the students.

Part c) **u14q04_3**

		Frequency	Percent
Valid	0	2	,4
	3	1	,2
	4	4	,9
	5	4	,9
	6	3	,7
	7	4	,9
	8	3	,7
	9	5	1,1
	10	21	4,7
	11	97	21,7
	12	254	57,0
	missing	48	10,8
	Total	446	100,0

Table 3.13: *This table is the results of the answer frequency in part three of question 12 which is about finding the best mathematical expression which refers to the graph III. Numbers 3 to 12 refers to mathematical expression alternatives in the question. According to this table the most frequent expression is 12 “y=a” which refers to a straight horizontal line. The most frequent wrong answer is alternative 11 “y=x” which refers to a straight line through the origin. This result may show that there are many students who don’t know what the difference between expressions 11 and 12 is.*

Answers

The first group gave the correct answer (expression y=a) to this part that was about finding the correct mathematical expression between the twelve given options that expresses the graph 3 best. They didn't have any discussion about this part in the group. One of the students suggested y=a (12) and the other participants in the group accepted that answer without reasoning. It seemed to be an easy question for them.

The second group gave the correct answer to this part as quick as the former group without reasoning and without discussion. It may be a sign that the students just began a discussion when they are not sure about the answer or solution of the problem

In the third group, there were some students who were not sure about the correct answer. First, one student suggested the correct answer which was expression "12"(y=a), but another one suggested alternative "11" which was "y= x". There was a discussion in the group about these two options. At last the student who had the wrong thinking was shown, with using examples, by the other students why her answer wasn't correct:

> Jente: *"du må jo ta "x" for "a" er ikke samme heletiden. Hvis stigningen er null ikke sant, "y" er null."*
> Gutt: *""y=x" er et punkt. "y=x" må jo være et punkt.*
> Jente: *"Nei, "x" skifter heletiden. "x" er jo (...)."*
> Gutt: *"(...) så er det 5 så er det jo "y", 5 og "x", 5"*
> Jente: *" Oh ja ja"*

The forth group gave correct answer with giving the reason that it was clear from the graph that the mathematical expression which refers to this graph should be constant.

As mentioned above three of four groups answered correctly to this part without any special discussion or reasoning. The group three answered correctly too, but they had a discussion which showed some of the participants in the group were confused between alternative "11" which was an expression to a point and "12" which was expression to a straight line. Guttersrud's (2008) data shows that there is 57 % frequency of alternative "12". Frequency of alternative "11" is 21.7 %. It may indicate that the students in his study didn't know either for sure what the difference between an expression for a line and an expression for a point was actually. The problem can go back to the mentioned point that the students don't have enough knowledge about component of mathematical expressions and therefore can't connect a given expression to right graph that refers to that expression or vice versa.

Part d) **u14q04_4**

		Frequency	Percent
Valid	0	3	,7
	1	35	7,8
	2	145	32,5
	3	58	13,0
	4	31	7,0
	5	13	2,9
	6	40	9,0
	7	33	7,4
	8	9	2,0
	9	4	,9
	11	1	,2
	12	3	,7
	missing	71	15,9
	Total	446	100,0

Table 3.14: *This table is the result for the answer distribution in the last part of question 12. In this part students were supposed to find the correct mathematical representation form which refers to the graph IV. Alternative 2 "$y=-ax^2+bx+c$" with 32.5 % is the most frequent correct answer which is the highest frequency in this results table. 16% is missing and 13% answered alternative 3 ("$y=ax^2-bx+c$").The difference between expressions 2 and 3 is in the signs of "b" and "a" and this may show that the conception of "a" is also difficult to understand for students.*

The first group didn't discuss much about this part which is about finding the best expression that can express the graph IV from question 11. One of students mentioned the point that the right answer should be an expression with negative "a" and gave the expression "$y= -ax^2+bx +c$" and this matched with the expression number 2 among the given expressions. They didn't discuss about the sign for "c". Maybe because they had in mind that "c" had positive sign in the given graph?

The second group gave correct answer in this part with good reasoning. This can show that they knew what "a" and "c" refers to.

The third group didn't give a correct answer. Since they didn't know what the characters "a", "b" and "c" meant. They tried to remember from what they had learned before, but it didn't work either.

Jente: *"For den er flest graf som liknet på graf "4" vi har brukt tidligere og da er det hatt funksjon som ser ut som funksjon 3. det er alt grunnen. Jeg har ikke noe mer logisk forklaring om hvorfor det er det liksom."*

According to Guttersrud's (2008) learning strategies, the students try to use "memorizing" learning strategy here. Lemke (2003) also means that it is a principle, in literary theory, which says that we make sense of each item we read or hear or see partly by comparing it with other things we have read, heard, or seen somewhere else.

The forth group gave correct answer. They were sure about that the correct answer should be one of four alternatives at the first line (“1”, “2”, “3” and “4”).Between “3” ($y= ax^2-bx +c$) and “1” ($y= -ax^2+bx –c$) they didn’t choose “1” because of the sign of “c” which was negative. Afterwards they found out that “a” should have negative sign then they chose option “2” ($y= -ax^2+bx +c$) which was correct answer.

Discussion in the first group showed that they knew what component “a”, in the expression, meant and which role the sign of “a” could play in the graph referred to the given mathematical expression which “a” is a part of it. Group two and four answered correctly too and their argumentations showed that they knew about the meaning of “a” and “c”. It was the group three which answered wrong, expression “3”, which was the common wrong answer with a frequency of 13 %, in Guttersrud’s (2008) study. That group admitted that they didn’t know what “a”, “b” and “c” meant. According to the data from Guttersrud (2008), in his study there were 32.5 % who gave correct answer . This is a low percent, and may show that this item was not so easy to the students in his study.

Question 13: SEA LEVEL

U14Q05 concept/exper; conclude and com

– 01 02 03 04 11 12 13 21 22 23 29 99

Write down how the sea level can change if the average temperature on Earth increases. Use the information from the experiments with **glass 1 and 2** and the **bottle with the straw**:

....

....

....

u14q05

		Frequency	Percent
Valid	1	51	11,4
	2	9	2,0
	3	34	7,6
	4	26	5,8
	11	67	15,0
	12	93	20,9
	13	5	1,1
	21	4	,9
	22	64	14,3
	23	13	2,9
	29	4	,9
	missing	76	17,0
	Total	446	100,0

Table 3.15: *This table shows frequency of the answers by students to question 13 that asks the students about the change in sea level if the average temperature on Earth increases. The answers are coded: 1 - 4 and 11, 12, 13, 21, 22, 23, 29 and "missing". There is more detail about how these codes are categorized by Guttersrud (2008) in appendix 2. The most popular answer according to this table is the answer coded 12 that includes the answers which refers to rising of the water because of the water expands or the density of water decreases. The most frequent wrong answer is the answer coded 11 that refers to answers which include just the aspect that means the sea level rises because of the melting of the ice in the South Pole or/and melting of glaciers. The other popular incorrect answer is the answer coded 1, which include statements that refers to the sea level rising because of ice (at the "poles" or the North Pole) melting.*

In this question students are supposed to interchange between conceptual and experimental representation forms and they are supposed to use “conclude and communicate” reasoning process (see 1.4.2).
The form of this question is different form the other questions used in this unit this is an open question and the students are supposed to interchange between conceptual and experimental representation forms. The students are supposed to interchange between the mentioned representation forms by using the reasoning process marked as “conclude and communicate” which means drawing and communicating valid science-based conclusions anchored in empirical data and evidence provided. Also the students are supposed to make and communicate scientific explanations to justify solutions.

Answers

The correct answer in this question has three aspects:

1. The sea level rises because of melting of the ice at The South Pole and/or glaciers melt
2. The sea level falls until all melted water have reached a temperature at 4 ^{0}C
3. The sea level rises because the water expands/ the density decreases (above 4 ^{0}C)

The first group gave a correct answer including aspects 1 and 3(code 22, Guttersrud’s (2008) scoring system).They didn’t mention explicitly 4 degree. This group didn’t talk about the experiment and just evaluated the answer in relation to the real world. With other words this group has not used the experimental representation form as it was expected from them.

The second group gave a correct answer with discussing about aspects 2 and 3 (code 23, Guttersrud’s (2008) scoring system). In this group they tried to use the information they had from the experiment as expected. This means that they have not used the experimental representation form. They just have used the conceptual representation form.

The third group gave a correct answer too using discussion almost the same as the second group, but here they didn’t use the information from the experiment.

The forth group gave an answer like groups 2 and 3, but here like the third group the students didn’t talk about the experiment. This means that they just used conceptual representation form during their discussions.

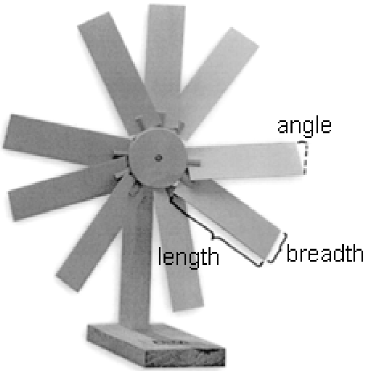
Three of four groups here used just conceptual representation form in their discussions. The reason that they didn’t use experimental form could be that this question was actually about the real world. The students may not have noticed the last part of the question which wants students to use the information from the experiments or their lack of knowledge about interchanging between the experimental and conceptual forms leaded to this results. The answers of all four groups got full credit according to Guttersrud’s (2008) scoring system. The first group has got code 22 (Aspects 1 and 3 correct only) which refers and the other three groups had got code 23 (Aspects 2 and 3 correct only and possibly that the sea level rises because ice, at the poles or The North Pole, melts). In Guttersrud’s (2008) data the most given answer was code 12 (Aspect 3 correct only and possibly that the sea level rises because ice, at The North Pole, melts) with 20.9 %.and the code 22 was14% and code 23, which was the most given answer in this study, was 2.9 %. Comparing of data from this study and Guttersrud’s (2008) shows students in these two studies may think different from each other.

3.4 Results and discussions of “WIND POWER” unit

WINDPOWER

Some students built a small windmill and attached blades with different length, breadth and angle to the mill. They used a fan with two speeds (high and low) as a wind source.

The students connected a generator to the mill to produce electric current, and they used a voltmeter to measure the mill's ability to provide electric potential energy. The diagram shows the results of students' measurements.

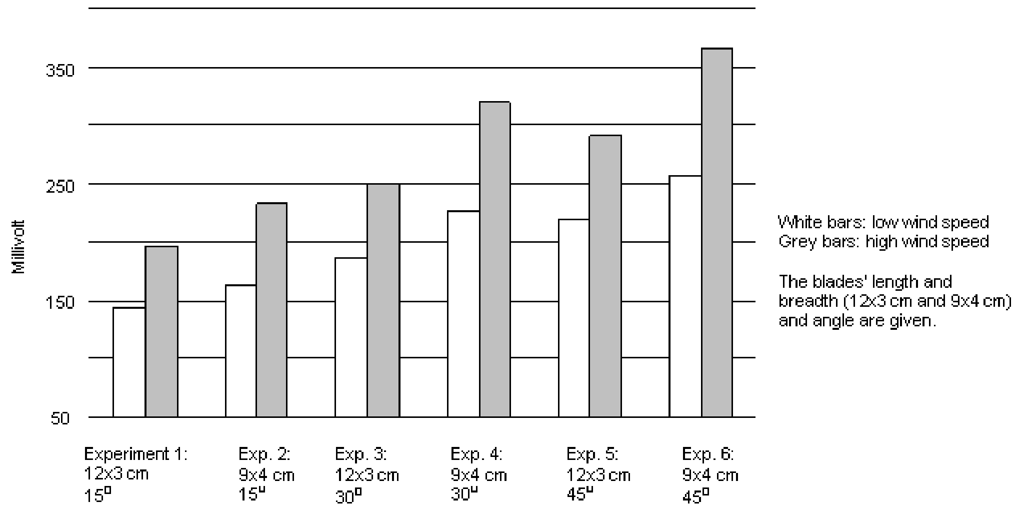


The students had three hypotheses they wanted to test:

1) A long blade produces more energy than a short at the same wind speed.

2) An angle of 45^0 is the most effective of all angles between 0 and 90^0.

3) Low wind speed provides less energy than high wind speed.



Question 25: WIND POWER *U05Q02 concept/exper; decide – 0 1 9*

To test their hypotheses the students had some variables (blades' length, wind speed) and some constants (blades' surface area).

What explained BEST why the students kept the blades' surface area constant?

A To keep the energy production the same at high and low speed.
B To keep the blades' energy production the same for long as for short blades.
C To keep the wind force on the blades the same at high and low speed.
D To keep the wind force on the blades the same for long as for short blades.

A

u05q02

		Frequency	Percent
Valid	0	12	2,7
	1	31	7,0
	2	59	13,2
	3	101	22,6
	4	198	44,4
	missing	45	10,1
	Total	446	100,0

Table 3.16: *In this table numbers 1-4 stand for alternatives A, B, C and D. The most frequent answer is the correct answer, D which says the reason is to keep the wind force on the blades the same for long as for shorts blades (44.5 %). The most popular distractor is alternative C (22.5 %). The answer option C says that student should keep the blades' surface area constant to keep the wind force on the blades the same at high and low speed. In this question, there are 12 students who have chosen two alternatives at the same time. This type answer is been coded 0.*

The students are confronting hypotheses which they are supposed to deal with during discussion of questions. Students are supposed to choose the best reason for why the blades' surface area should be kept constant during the testing of three hypotheses mentioned above in the experiment.
This question has expectation about interchanging between conceptual and experimental representation forms. The reason process expected from the students is "decide" category which means the students should select from alternative solutions and give explanations with respect to empirical data and evidence provided (see 1.5.2).

Answers

The first focus group discussed each option, but they didn't use much reasoning. They discussed also from the real life about turbines to take conclusions in relation to this question and it helped them a little bit. Afterwards they were not so sure between the options "C" (To keep the wind force on the blades the same at high and low speed) and "D" (To keep the wind force on the blades the same for long as for shorts blades), at the end they chose alternative "C", but they didn't have good reason for choosing this option.

The second group tried to use the information from the question and the given diagram to find the correct answer. They were busy with energy production instead of wind force. The reason can be the given diagram in the question which showed the energy produced by the blades. They at last gave wrong answer and chose alternative "B" (To keep the blades' energy production the same for long as for short blades).

The third group had a discussion using data from the given diagram and the question itself, but it seemed to be difficult for them to find the correct answer. They didn't have enough knowledge and at last decided not to give an answer at all.

The forth group didn’t discuss much about this question. They used data from the given diagram. They gave wrong answer with choosing option “C” (To keep the windforce on the blades the same at high and low speed). There was just one student who came with this answer and tried to argue for it. The others just agreed without discussion. There can be two reasons. The first one may be that the other students hadn’t any idea about the question and just accepted the given answer. The other one is that may be they agreed because they had thought the same and had the same answer to the question. In both cases we can conclude that the students hadn’t scientifically correct thinking process.

During the discussions about this question the students tried to use the expected interchange between representation forms, but they didn’t seem to have enough knowledge related to this topic. All the groups answered wrongly to this question which was somewhat surprising considering that 44% responded correctly in Guttersrud’s (2008) test. The most common distractor was alternative “C”. This was the same as in Guttersrud’s (2008) data where alternative “C” was the most popular wrong answer (22.6 %).The poor results in the groups in the present study show that students lack practice in reasoning.

Question 26: WIND POWER *U05Q04graph/exper; evaluate – 0 1 9*

Look at the students' measurements and decide whether the hypotheses **1** and **3** should be kept or not. Circle "Yes" or "No" for each.

Hypothesis	Should the hypothesis be kept?
A long blade produces more energy than a short at the same wind speed (hypothesis **1**).	Yes / No
Low wind speed provides less energy than high wind speed (hypothesis **3**).	Yes / No

This question, which is classified as "vector" (see table 1), included two hypotheses which students were supposed to evaluate and see if they should be kept or not, according to the data given in the experience and graph.

u05q04_1

		Frequency	Percent
Valid	1	106	23,8
	2	311	69,7
	missing	29	6,5
	Total	446	100,0

Table 3.17: *This table shows distribution of answers to question 26, part 1. Students are supposed to evaluate of the given hypotheses to see if they should be kept or not. In this part the hypothesis is that "a long blade produces more energy than a short at the same wind speed". Almost 70 % of students stated correctly that a long blade does not produce more energy than a short at the same wind speed (code 2). Almost 24 % responded that this hypothesis should be kept which is an incorrect answer (code 1.)*

Answers

The first group gave correct answer for this part. First they discussed based on their own knowledge and this led them to wrong answer. They tried in the second stage to use the information they had from everyday life. They used as example the windmills used in Denmark and said that their blades are very long. This example didn't help them either. Then they used information they got from the diagram in the question and discussed it. This time they got on the right track and gave correct answer.

The second group didn't discuss at all. One of the students meant they should not keep the hypothesis and the other students just stated his answer without argumentation.

The third group answered correctly to this question first from the data they had in diagram, but after more discussion they got confused and gave incorrect answer to this part.

The forth group discussed the question using the data they had gotten from the given diagram and it helped them and they gave correct answer to this part.

For the part most students in Guttersrud's (2008) study had given correct answer (69.7 %). In the present study there were three of four groups which answered correctly to this part. The students didn't interchange often between graphical and experimental representation forms as expected, but they used mostly just the graphical form and concluded based on the data given in the diagram.

u05q04_2

		Frequency	Percent
Valid	1	376	84,3
	2	42	9,4
	missing	28	6,3
	Total	446	100,0

Table 3.18: *This table shows distribution of given answers in question 26, part 2. In this part the hypothesis is "low wind speed provides less energy than high wind speed" and students are supposed to answer to see if they should keep the hypothesis or not. The correct answer here is that low wind speed provides less energy than high wind speed. The frequent for this answer is 84.3 % (code 1). The frequency for the wrong answer is 9.4 % (code2).*

The first group had a short discussion about this part and they gave correct answer. They had not good discussion in this part. It is possible that the discussion they had about the first hypothesis helped them to giving answer to this part too.

The second group first answered wrongly, but when they read the hypothesis again and they found out that they should change their answer and agreed about keeping the hypothesis.

The third group didn't give any answer to this part, they were confused after the discussion they had about the first part.

The forth group gave correct answer to this part but they didn't discuss the answer. Maybe the reason was the short discussion they had at the first part and they didn't need to discuss more.

Three of four groups answered correctly to this part of question and the forth group didn't answer at all. According to Guttersrud's (2008) data there were 84% who had answered correctly in his study. In this part students didn't discuss much. The reason could be that they regarded the answer as self-evident.

Question 27: WIND POWER U05Q05 graph/exper; categorize – 01 02 (03) 04 11 12 99

Hypothesis 2: "An angle of 45^0 is the most effective of all angles between 0 og 90^0".

Write down (in the vacant spaces) the numbers for three experiments at "high speed" that the students may compare to decide whether the data so far strengthen or weaken hypothesis 2:

Experiment number ____, ____ and ____.

This question is an example to see how students use interchanging between graphical and experimental representation forms. This question is classified as “short constructed response” (see table 1).The reasoning process which is expected to be used here is the “evaluate” category which means students should evaluate scientific claims with respect to empirical data and evidence provided (see 1.5.2).

u05q05

		Frequency	Percent
Valid	1	18	4,0
	2	33	7,4
	3	75	16,8
	4	8	1,8
	11	60	13,5
	12	189	42,4
	missing	63	14,1
	Total	446	100,0

Table 3.19: *This table shows frequency of answers to question 27. The codes 1-4 (null credit), 11 and 12 (full credit) are given to different answer categories. The most frequent correct answer is answer coded as 12, 42.4 %, which refers to experiments 2, 4 and 6 only. Code 11, 13.5 %, refers to experiments 1, 3 and 5 only. The most frequent wrong answer is code 3, 16.8 %, which refers to respondents who referred to experiment 4, 5 and 6.*

Here students are supposed to interchange between graphical and experimental form of representations with using the reasoning process named as “categorize” which have been discussed before. The students are given a hypothesis (2) and should write down the numbers for three experiments at high speed” that the students may compare to decide whether the data so far strengthen or weaken the hypothesis

Answers

The first focus group gave a complete correct answer to this question after a long argumentation. They used information from the given diagram and that helped them to answer correctly (code 11 which refers to experiments 1, 3, 5 only, see appendix 2 for more details).

The second group gave a complete correct answer too .The reason was that they also used the given data from the diagram and discussed them (code 12, refers to experiments 2, 2 and 6 only, see appendix 2 for more details).

The third group gave a complete correct answer, but they had a very short discussion over the data they had from the diagram. (code 12 which refers to experiment2, 4 and 6 only, see appendix 2 for more details)

The forth group gave the correct answer, but didn't talk about the other correct option and they had also too short discussion and that means that the students didn't take the experiment 5, which was shown in the diagram into consideration. (code 12 which refers to experiment 2, 4 and 6 only, see appendix 2 for more details)

Here three of four groups answers coded 12 (refers to experiment 2, 4 and 6 only, see appendix 2 for more details). This code was the most popular answer in Guttersrud's (2008) results (42.4 %). The first group's answer which was different from the others was coded 11 (refers to experiments 1, 3 and 5 only, see appendix 2 for more details). In Guttersrud's (2008) data there were 13.5 % who gave this answer. The groups mostly used the expected reasoning process, categorize (see 1.4.2).

Question 28: WIND POWER

U05Q06 graph/exper; conclude and com

– 01 02 03 04 05 06 11 21 22 9

Do the students have sufficient data to decide whether hypothesis 2 should be kept or rejected? Explain your answer.

....

....

This question is according to table 1 classified as “extended constructed response” .Students are supposed to interchange between graphical and conceptual representation forms. The reasoning process is supposed to be as “conclude and communicate” (see 1.4.2 for more details).

u05q06

		Frequency	Percent
Valid	1	40	9,0
	2	13	2,9
	3	83	18,6
	4	31	7,0
	5	47	10,5
	6	15	3,4
	11	20	4,5
	21	101	22,6
	22	8	1,8
	missing	88	19,7
	Total	446	100,0

Table 3.20: *The numbers in this table is for coded answers to question 28. Students have been asked to see if they have enough data to keeping or rejecting hypothesis 2, “An angle of 45^0 is the most effective of all angles between 0 and 90^{0}”. The codes: 1-6 refers to answers which get no credit according to Guttersrud’s (2008) scoring system. The code 11 gets partial credit.. The most frequent correct answer is the code 21 which refers to lack of data above 45 degrees and not able to decide (22.6 %). The most popular wrong answer is answer coded as 3 which refers to answers saying data is sufficient to decide with or without explanation (18.6 %.).*

Answers

<u>The first focus group</u> gave correct answer which was about not having enough data for angles more that 45. This type of answer gets full credit with code 21 which refers to lack of data above 45 degrees and not able to decide (see appendix 2 for more details).

The second group gave an incomplete but partly correct answer. They discussed about not having enough data but didn't name explicitly what kind of data they would need to answer the question. Therefore their answer was categorizes at code 11 which refers to insufficient data ant not able to decide (for more details see appendix 2).

In the third group, one student suggested to keep the hypothesis which wasn't a correct answer. Another student talked about that they hadn't enough data which was a correct scientific thinking. But the third one began to discuss about the reasoning for the 45 degree was the most important angle. He said there was no possibility to test bigger angles that 45 degrees. His idea led the whole group's meaning and they agreed with him. The group's answer to this question was wrong (code 04 which refers to keeping the hypothesis OR that the hypothesis is "correct" with the explanation that the angle 45 degrees produces most energy, see appendix 2 for more details).

The forth group gave a correct answer by discussion about not having enough data above 45 degrees. Like the first group they got score code 21 which refers to lack of data above 45 degrees and not able to decide (see appendix 2 for more details).

There were two groups of four groups which gave a full answer and got full credit or more precisely code 21(refers to lack of data above 45 degrees and not be able to decide) from Guttersrud's (2008) credit system (see appendix 2). According Guttersrud's (2008) data there were 22.6 % who got code 21 and that was the most frequent answer by the students in his study. The other answers we had here from the two other groups were code 4(refers to keeping the hypothesis OR that the hypothesis is "correct" with the explanation that the angles 45 degrees produces most energy, see appendix 2 for more details) which was 7% in Guttersrud's (2008) data and code 11 (see appendix 2) which was 4.5 % in his data. The reason that the students didn't give fully correct answer may be the lack of knowledge in this topic.
The results from this question showed that there was 50% fully correct answer. In relation to the supposed reasoning process, conclude and communicate which is described before (see1.4.2), the students mostly had this kind of reasoning process but it wasn't always based on correct scientific explanations.

3.5 Summarizing the results from the five code families

3.5.1 Types of representational approach (Family A):

This family is supposed to give us an overview on communicative approach which students use during the focus group studies. First of all I'm going to give a quantitative result of coding in a table. This table shows how many quotations are linked to each of the codes in this family.

Code	The number of quotations
Communicative_authoritative/single	19
Communicative_authoritative/multi	84
Communicative_Intuiitiv/single	50
Communicative_Intuitiv/multi	18

The results from group discussions show us that students use the authoritative-multiple representation forms much more than the other three classes in this coding family (84 quotations). With other words, students mostly interchange between different representation forms in a correct scientific way. 68 quotations in the whole interviews were included scientific incorrect interchanging the representation forms. This may show that good students are able to work with several representation forms simultaneously and to use them correctly. On the other hand they talk mostly in incorrect scientific way when they use just one type of representation form. At the same line as, Lemke's (2003) findings show that every scientific concept is an element in a system of signs, and it is an integration of simultaneous and conjoined elements in several very different systems of signs. He means that the meaning of a scientific concept does not arise simply from each of these signs, but it arises from the combination of all of them. The single representation forms which they use often are conceptual and experimental form. The exercises are made in a way that students are expected to interchange between representation forms during discussing them. Therefore using just one form of representation form which is almost 40 % from all the talks including representation forms should be paid attention. One reason can be that it is difficult for students to connect theory and experiment in these cases. When students are tending not to interchange between representations, it shows that their abstract physics ideas are not connected to experiences from real world (Leonard, Gerace, Dufresne, & Mestre, 1999). In results it was obvious that students use mostly conceptual or experimental representation forms when they use single form of representation.

Another interesting result was that when students exchange between representation forms they use more scientific correct idea than when they use a single form. Maybe it is possible to say that exchanging representation forms give the students better ability to use scientifically correct ideas or as mentioned earlier in this part that good students use interchanging representation forms correctly.

Here are some examples of each type:

Communicative_authoritative/single: Just one representation form and scientific correct idea.

> Gutt: *"det gjør noe at det blir mer luft i vannet, da blir vannet større eller det ser større ut… det er ikke mer vann, det bare ser større ut…"*

Communicative_authoritative/multi: interchanging between representation forms and scientific correct idea:

> Gutt: *"Glass 1 er I hvert fall y=b"*

This student interchanges between conceptual and mathematical representation forms and at the same time it is scientifically correct.

Communicative_intuitiv/multi:

> Jente: *"Den der delen ikke jeg forstår nei, hvis vi prøver å dra den med konstant akselerasjon så burde den bare fortsette oppover en rett linje… burde ikke?"*

This student interchanges between conceptual and graphical with talking about acceleration and how the graphical form should be like, but she uses incorrect scientific form because if the acceleration is constant then the graphic form should be a horizontal line.

Communicative_intuitiv/single:

> Jente: *" Når farten er konstant så er det jo akselerasjonen konstant"*

This statement is an example of the use of conceptual representation form incomplete. This representation form has been use scientifically incorrect here.

3.5.2 Types of content (Family B):

This family, which included 5 classes, is provided to evaluate the content of the focus group interactions. The results of the number of quotations are:

Codes	The number of quotations
Content_emperical/description	12
Content_empirical/explanation	10
Content_theorethical/generaizationl	59
Content_theorethical/description	29
Content_thorethical/explanation	38

According to the results the students talk more using theories in physics or mathematic in its general form. Here is an example where they use the theory: “acceleration is going to be zero if we have constant speed” independently of any particular context.

> Gutt 1:”*De to andre derimot er feil ettersom akselerasjonen i eller ved konstant fart er null…”*
> Gutt 2:”*Akselerasjonen er jo ingenting… også den finnes ikke…”*
> Gutt 1: *”så derfor…”*
> Jente: *”Så da kan vi ikke ha noe graf…”*

Another perspective here is that the students use more theory than empirical category, 85% against 14%. Angell et al (2004) pointed out that Norwegian physics students had a weak understanding of the role of experiments in physics and that physics teaching has a traditional form focusing on content (conceptual) knowledge rather than for instance experimental approaches. The reason behind this result here may also be that the students are more familiar with theory than empirical features in physics. They use the theoretical-explanation category more than theoretical-description. The difference between these categories is that explanation feature shows a relationship between physical phenomena and concepts while description concept issued when they don’t involve a proposed mechanism for explaining the phenomenon. This means when students use theory in its specific form, explanation or description, they use more phenomena-concept related statements than not mention any mechanism to explain a phenomenon.

3.5.3 The form of students’ arguments (Family C):

Codes	The number of quotations
Intervention_cumulative	59
Intervention_disputational	30
Interv_exploratory	62

Results from the focus group studies showed that the most popular type of intervention is exploratory which includes explaining and reasoning. Cumulative intervention which involves statements showing repeating and confirming comes in second place. They have disputational type of interventions in almost 20% of their talks. This may show that the students don’t have much new ideas while discussing the questions but they rather use either the same idea from the question or just confirm what other participants say. Another point is that maybe the students are not willing or confident enough to challenge suggestions from their peers. Here follows one example sequence of each intervention type:

Intervention_cumulative: Repeat-Confirm-Elaborate

Gutt1: *"Glass 1 er i hvert fall y=b "*
Gutt2: *"Ja helt sikkert, det må være…"*
Gutt1: *"A høres mest riktig ut fordi at y=b og fordi at y=ax+b er det vannstanden før isen begynte å smelte…"*

Intervention_disputational: Claim-Counterclaim-Challenging question

Gutt1: *"ax I annen pluss bx pluss c da…"*
Gutt2: *"Nei jeg tror at graf nummer 2 er nummer 4 sånn er det annen grads likning fordi den er…ja…"*
Gutt3: *"Hva er C?"*
Gutt1: *"C er konstant (...)"*

Intervention_exploratory: Explain-Reason-Offer alternative solution- Challenge backed up by evidence/reasoning

Gutt1: *"Hvis y er lik x så hvis vi sier y er 5 da så må jo x også være 5 da…da blir det et punkt."*
Jente: *"Men hvis y er a og her er a null…"*
Gutt: *"Ja da blir det null (...)bortover…"*
Jente: *"Ja, men da må y også være null…"*
Gutt: *"Nei nei, men det er y og det er x og a er bare tall…"*
Jente: *"Ja a er det tall og på den grafen her så er det null…"*
Gutt: *"Nei. Det er jo grafen."*
Jente: *"a er bare tall og hvis den (...) da går den bortover 5, fordi du ikke har x (...) fordi det er (...) men ikke verdiene er samma… så blir det 12ern… blir ikke det?"*

3.5.4 Types of argument (Family D):

This family includes 3 classes to show a content of argumentations is about Physics, mathematic or just every day features.

Codes	The number of quotations
argument Type_physics	110
argumentType_mathematics	41|
argumentType_everyday	7

The distribution of results from this coding family was: 25% mathematical, almost 70% physics and almost 4% everyday argumentation types. It shows that the students use to a very little extent every day type of argumentation. This can mean that they don't relate experiments to real life experiences. The car unit can be said is more theory and since students are used to such exercises, they discuss this unit in theory form and use mostly physics or mathematics argument types. It was supposed that students use more everyday type argument about the other two units, sea level and wind power since they are more about topics which students could have heard from outside the school, especially sea level as one of the students confirm this aspect during the interview:

> Jente: *“Ellers så var det den der om havnivået stiger eller synker, det var litt morsomt … i hvert fall nå… det er veldig aktuelt… man skjønner jo at den stiger… så akkurat det var ikke så… men det å begrunne det var det kanskje litt…”*

Examples of each argument type:
ArgumentType_physics:

> Gutt: *“Ja, men den smelter så smelter ved null… altså … blir tettheten større til 4 grader… je … samme da…”*

ArgumentType_math:

> Gutt: *“A høres mest riktig ut fordi at y er lik b og fordi y er lik a ganger x pluss en b, er det vannstanden før isen begynte å smelte.”*

ArgumentType_everyday: In this example, one student is talking about the windmills that are in Denmark, during talking about the windmill unit:

> Gutt: *“Nei… ikke sant hvis vi ser på ja Danmark da har de kjempe lange…”*

3.5.5 Type of interchanging between representation forms (Family E):

This family shows which kind of interchanging the students have used during the solving of exercises. There were total 20 codes in this family from which just 12 have been linked to the suitable quotations during the analyzing process.

The used Codes	The number of quotation
Multi_ConceptExp_authoritative Multi_ConceptExp_intuitive	11 5
Multi_ConcepGrap_authoritative Multi_ConcepGrap_intuitive	29 14
Multi_ExpGrap_authoritative Multi_ExpGrap_intuitive	12 17
Multi_MatConcep_authoritative Multi_MatConcep_intuitive	12 6
Multi_MatExp_authoritative Multi_MatExp_intuitive	5 1
Multi_MatGrap_authoritative Multi_MatGrap_intuitive	15 12

The point which is remarkable in this table is that ExpGraph and MatGraph are the only two where intuitive approaches are used more often or almost as often as authoritative. This is in line with Guttersrud's (2008) finding that students have difficulties with appreciating the role of graphs as mediators between experimental results and mathematical expressions.

The main code categories of interchanges between pairs of representations were constituted based on the five forms of representations described earlier (at method). To see if the students use these interchanges in correct or incorrect way each of codes divided into two, intuitive which means uses of interchanging in an incorrect way and authoritative which means correct use of interchanging of representation forms. Each question used in this study is marked with an interchange which students are expected to use during discussion of problems. These interchange alternatives are: Conceptual/Graphical, Mathematical/Experimental, Conceptual/Mathematical, Graphical/Experimental, Mathematical/Graphical and Conceptual/Experimental. The results the study gives us are that the students use just these interchanges options. This can indicate that students to large extent did know what they were doing. The question is however if they are using the interchanges scientifically correct or not. There were 65% authoritative against 35% intuitive answers. The most used interchange was Conceptual/Graphical and the least used was mat/exp. The option which had the nearest distance between correct and incorrect alternatives from an interchange type was mat/graph and the one which had the farthest distance was mat/exp. Maybe it is difficult for the students to relate mathematical representation form with graphical at the correct scientific way.

Here is an example of coding results from the code: E_multi_ConcepGrap_aut. This statement is from a student answering the question about choosing a graph of four graphs that is the right graph showing height of the water in a bottle as a function of the temperature when temperature changes from 0 ^{0}C to 20^{0}C:

> Jente: *"Da tror jeg det må være graf nummer 2…fordi vannet har størst tetthet på 4 grader…"*

Here she interchange between graphical representation form and conceptual when she is talking about the graph and density of water at 4^{0}C and uses this in a correct way.

Another example is a result of coding with: E_multig_ConcepGrap_intui. Here students in another focus group answer to the same question as above with these statements:

> Gutt1:"*Vannet stiger (…) etter hvert*"
> Gutt2: *"Den stiger (…)"*
> Gutt1: *"Det er ikke noe sånn hjooo så er det bare plutselig ferdig (…)"*
> Gutt2: *"Jeg tror den er 1ern."*
> Gutt1: *"Jeg er overbevist."*
> Jente: *"Ja"*
> Gutt1: *"Vannet synker ikke først"*

Here they talk about conceptual when they say that the height of water increases and they use graphical form referring to a graph in their statements. We have an interchange between conceptual and graphical representation forms, but since it isn't happening in reality because of the fact that water has the highest density in 4^{0}C and that means the height of water doesn't just increase, then they have used incorrect scientific reasoning.

3.6 Results from the questions in interview guide

Interview guide (appendix 3) as mentioned in the method chapter in this study, included some questions about students' views on experiments in physics. Here are the results from that part of interview. The Atlas program hasn't been used during analysing of this part. Here I have gone through the interviews with the focus groups and extracted the interesting points related with the focused themes in this study.

3.6.1 Students' point of view about physics

During interviews I found out some students were more used to calculating in physics rather that evaluate mathematical models or in other words practical physics. When students were asked what they think about the questions, some of them answered:

> Jente: "*Ellers var de annerledes … jeg som ikke er vant til å sitte og regne på ting. Her skal du bare vurdere hvordan de er kommet fram til ulike ting… også de er vist annerledes fra de som vi er vant til da…"*
>
> Gutt: *"Det er litt mer sånn faktisk tenkning da… fysikk er mer tradisjonelt bare å regne opp… du skjønner litt mer selve faget ja… skjønner litt mer hvorfor de… og hvordan de fungerer…"*
>
> Jente: *"Det er litt mer praktisk…"*
>
> Gutt: *"Det er ikke bare sånn du setter inn tall…"*

Students' answers to the questions showed that some of them had a picture of physics in their mind, which was different from physics they faced during doing the exercises and they name the picture sometimes usual physics. When I asked how they felt about these exercises, one of them said:

> Gutt: *" Jeg synes det var en opplevelse… mye bedre enn vanlig fysikk…"*

An interesting point was that one of students mentioned that they should have learnt physics in a more practical way:

> Jente: *"Ja bare vi konsentrerte oss om bare regningen… vi har ikke lært så mye om å forstå og hvorfor blir dette her sånn hvis det er graf og sånn…*

3.6.2 Students' opinion about "THE CAR" unit

This unit is different from the other two in the way that students have had some similar exercises in their physics lessons. They express their ideas about this unit with these sentences:

Jente: *" Vi har jo hatt om ... grafer og lese de og ... ja liknende oppgaver*"

When I asked them directly if they have had some exercises like these before I got these answers:

Jente 1: *"Ja."*
Jente 2: *"Noen av dem ... ikke alle..."*
Jente 1: "*Nei i hvert fall på grafene... på bil oppgaven og sånn*"
Jente 3:"*Hva som viser akselerasjon og sånne ting..."*
Gutt: *"Ja."*

Jente: *"Ja, de grafene på side 2 er jo sånn som vi hold på med i begynnelse..."*

Even though they should be used to this kind of exercises one of them says:

Gutt: *"Akselerasjon oppgave det med tauet... det var litt sånn... spørsmål 3 på bilen ... det var litt ..."*

Another student follows him saying:

Jente: *"Man trenger tid til å sette seg inni den tror jeg til å forstå den da..."*

But there are some who think this unit is the easiest one:

Jente: "*jeg synes bilen var letteste jeg."*

3.6.3 Students' idea about the discussions they had during solving the exercises

Some of the students' expressions show us that they think discussing is useful and they have learnt of talking in group:

Jente: *"... men jeg synes det er deilig sånn å jobbe sammen som man kan diskutere om det... jeg er ikke så egentlig glad i grafer og forklare ting og sånn ... men jeg tror man lærer veldig mye av den..."*

Gutt: *"Ja ja, jeg er enig om det... det er greit å kunne diskutere..."*

And when I asked how working with these exercises was for them one of them answered:

> Jente: *"Det var helt greit… vi fikk jo diskutere og det var veldig bra."*

Also the FUN study (Angell et al., 2004) showed that physics students would like to use discussion more frequently when learning physics.

3.6.4 Students' views on graphs

The interpretation of data and interpretation of graphs are central practices in science (Bowen & Roth, 2005). When interpreting a graph in physics, a student must be able to determine which features of a graph correspond to particular physical concepts (McDermott, Rosenquist, & Zee, 1987). According to these authors, an important reason and motivation for investigating about skills of students in interpretation of graphs is the fact that skills in drawing and interpreting graphs is of critical importance for developing an understanding of many topics in physics.
The graphical representation in modelling experiments is an effective way to connect the "real world" and the "abstract world" (Guttersrud, 2008).According to Bowen graphs are useful tools in representing the qualitative and quantitative aspects of nature. Graphs are abstract (Leonard et al., 1999), but interpreting them may be in a way that they act like intermediates between "the two worlds". Some of students had the same meaning about abstraction of graphs:

> Jente: "*Det er jeg litt enig at… det som på en måte vet hva litt mer er … de grafene er veldig abstrakte"*

When I asked them what they mean about different representation forms and their connection they used these sentences to explain their ideas:

> Gutt1: *"Kan bli forvirrende."*
> Jente: *"Det kan bli veldig vanskelig…"*
> Gutt2: *"Abstrakt."*

> Gutt: *"Jeg synes det er vanskelig med grafene … jeg synes* det er vanskeligst *egentlig."*

There are different meanings about why graphs can be difficult to students. According to McDermot (1987) there are some aspects of problems that students have with graphs. He means the problems students have with graphing cannot be simply attributed to inadequate preparation in mathematics, therefore there must be other factors which don't have mathematical background, that are responsible. The results of his study indicated that many of these difficulties about graphs and graphing are a direct consequence of poor ability to make connections between a graphical representation and the subject matter it represents. He gives two categories of student difficulty: difficulty in connecting graphs to physical concepts and difficulty in connecting graphs to the real world (McDermott et al., 1987). In this study, these two aspects were obvious during the students' discussions.

According to Foster (2004) the reasons why the students in her study did not succeed in the graphing questions mainly resided in students' non- familiarity with phenomena, physics principles and definitions. Here we saw that these reasons were among the reasons why the students had difficulties with answering graphical questions.

But some of the students said using graphs makes it easy to understand situation.

> Gutt: *"Man ser jo mer sånn umiddelbart hvordan sammenhengen er når man ser på en graf enn når man ser på formelen… ikke sant?"*

Two of the answers to a question about what their idea is about describing a phenomenon with words, graphs or mathematical formulas, was:

> Gutt: *"Med grafer er veldig lett… men om formler så er det litt vanskeligere."*
>
> Jente: *"Det er litt på en måte å forstå det på da… hvis vi skulle sett formelen for seg liksom så ville man kanskje ikke forstått så mye, men når det er forklart med ord og med graf også… så er det på en måte det er lettere å se sammenhengen da."*

Students should be able to represent real systems graphically and to visualize a system from its graphical representations (McDermott et al., 1987). Our interviews indicated that most of the students had trouble in each of these areas.

3.6.5 Students' views on models and modelling

There was a direct question about what they related to the word model. Most of the students had an idea about the model. Here comes some expression to show what they mean about model:

> Gutt: *"Noe som beskriver litt mer enn bare ord sånn at du kan se hvordan (…).*
> Jente: *"Modell ja… nei… det ja … Noe som beskriver noe litt mer fysikk enn bare…."*
>
> Gutt: *"(…) sikkert.. så er det jo… modell er det jo en presentasjon er ikke det?"*

When I asked them what they think about model and modelling some of them took the functional perspective of model and modelling .Here are some points of views which the students had about the function of model in related to learning physics

> Gutt: *"Det hjelper jo å skjønne jo…."*
> Gutt: *"At det gjør lettere å se tingene."*
>
> Gutt: *"Ja … for å kanskje gjøre fakta og tall og sånn om til noe vi kan se…."*
> Jente1: *"for å gjøre den forståelig…"*
> Jente2: *"Eller for å gjøre om vi kan se til fakta og tall…"*
>
> Jente: *"Som et hjelpemiddel da"*

The students' statements about model and modelling are almost in line with researchers' ideas in this area. According to Andaloro (1991) a model is a surrogate object, a mental and/or conceptual representation of a real thing.

3.6.6 Students' views on representation forms

There was a question about what they think about the connection between three different ways of describing the same phenomenon, concept, graph and mathematical formulas. Some of students answered by talking about one of aspects and some of them used expressions about the relation between them.

These students see each perspective separately:

> Gutt: *"Med grafer er veldig lett…, men om formeler så er det litt vanskeligere…"*

> Gutt: *"Jeg er mer glad i formeler enn sånn... grafer"*

In this chapter all the discussions during the focus groups' interview have been analyzed and discussed from different points of views. The views and ideas about representation forms and modelling and reasoning process during answering the questions were the important themes which have been taken to consideration here.

4 Implications and conclusion

This study explored student's reasoning process while solving the given physics problems in group. The points which were important to evaluate were: how the students use different representation forms, how they use scientific reasoning related to the problems and how they relate mathematics to physic during their problem solving process.

4.1 Learning science

Science learning has several functions to perform (A.M.A et al., 1970)

- give students a lasting understanding of what it means to approach a problem scientifically
- give students opportunities to observe and explore so that they can develop critical and imaginative thinking

An important question related to learning science is how science can be learned effectively. Constructivism is an influential view of learning. Two main features common among constructivists are: first, that learning demands the active intellectual involvement of students; second, that the students' prior knowledge influences subsequent learning of scientific concepts (Mortimer & Scott, 2003).

In this study we can see how students' involvement and their prior knowledge influence their learning. The results from interviews show that the students who had scientifically correct ideas as their prior knowledge were more able to carry out logical discussions than those students who didn't have such ideas in their minds before starting to the focus group study.

Importance of teaching /learning of model and mathematical modelling in learning physics

To teach the concepts of model and mathematical modelling, the PHYS 21 approach was to emphasise multiple representations and teach students skills of scientific reasoning (Guttersrud, 2008).

Gutterud (2008) uses expressions "external" and "internal" representations . Based on Dufour- Janvier et al. (1987) he gives definition of internal representations as mental images and external representations as all "external symbolic organizations" like physical objects, pictures, spoken language and written symbols. Afterwards, he uses suggestions from Heibert & Carpenter (1992) to discuss the relationship between internal and external representations:

> *"We may quite intuitively hypothesize that there must exist relationships between internal and external representations, that internal representations can be interconnected and take part of mental networks of knowledge, and that these networks can be constructed by making connections between corresponding external representations" (Guttersrud, 2008), p.142*

Therefore, it is interesting to see students' abilities to interchange between external representations when solving problems as expressions of their internal representations. According to Guttersrud (2008), a useful way to describe understanding of models of physical phenomena is in terms of mental models and in more detail is in terms of how individuals construct, connect and translate among their internal representations producing internal networks of knowledge.

From the data gathered in this study, it appeared that it was mostly difficult for students to interpret a physical situation in terms of mathematical relationships.
"Mathematical modelling competency" is considered as ability to reason scientifically and to interchange between multiple representations of a phenomenon (Angell et al., 2008b)
The ability of 'seeing' a graph of and a mathematical relationship between relevant variables and the 'simultaneous' application of and interchanging between the forms of representation during experiencing a phenomenon, is an ability which distinguishes the trained physicist or physics student from the novice (Angell et al., 2008b).

In PHYS21 there were two main arguments for a modelling approach to physics teaching: One of them was the perspective which concerned modelling as a powerful tool in the teaching and learning of physics or with other words using modelling as a method to teach physics content. Classroom observations and teacher interviews show clearly that this tool was found most attractive by the teachers (Angell et al., 2008b). The other argument concerned the nature of science: If physical science may be viewed as a "modelling enterprise", this should be reflected in physics teaching. This view was to a smaller extent taken up by teachers (Angell, Kind, Henriksen, & Guttersrud, 2008a)

There has been done some research about mathematical modelling, and many researches have argued that mathematical modelling of the physical world should be the central theme of physics instruction (Hestenes, 1987; Oke & Jones, 1982).

Relation between argumentation and the development of scientific knowledge

Although physics students in the present study appear to be happy with discussion in group, they are not so good at reasoning and they don't seem to be used to this method.

Although the importance of learning to develop valid arguments and also learning science while arguing has been focussed on within the last years (Osborne, Erduran, & Simon, 2004; Pinto & Couso, 2007), the interrelation between argument and content specific knowledge in teaching and learning has not been explored in great detail. The main questions concerning this interrelationship according to Pinto and Couso (2007) are:
How much scientific knowledge is needed to perform a valid argument? Furthermore,
How does the performance of argumentation influence conceptual understanding? And
how does the lack of content knowledge limit performance on argumentation?

The data from this study indicated that the students' lack of knowledge limited argumentations to some extent. On the other hand, the performance of argumentation influenced the conceptual understanding. In some cases a good argumentation led to better understanding of the conception. There were, in contrast, some arguments which were not based on scientific reasoning that led to confusion among the participants. Students should understand the importance of argumentation in relation to scientific aspects. It is also important that students learn how to argue and have practice of reasoning during their physics courses.

The role of representation forms in learning physics

It is a fact that working with physics always involves working with representations of a physical phenomenon (Angell et al., 2008b) According to Ainsworth (2000) a justification for using more than one representation is that this is more likely to capture learner's interest. He means using multi- representation forms plays an important role in promoting conditions for effective learning.
(How we can help the students to understand multiple representations) : Effective science learning by catering for students' individual learning needs and preferences and promoting students' active engagement with ideas and evidence can help on students' understanding of multiple representations (Prain & Waldrip, 2006).

These results indicates that students use mathematical representation form during their discussions in problem solving process, but it seems to be difficult to them to translate mathematical language to conceptual language or vice versa. Along similar lines, Dolin (2001) has suggested that physics' difficult aspect is that it requires students to deal with representation forms and to handle the translations between these.

The discussions related to the problems used in this study showed that the students can not to any large extent interpret the given graphs. The importance of the ability of interpretation of graphs in terms of mathematical expressions and physical quantities is an important skill in physics, and it has been shown repeatedly that Norwegian physics students have problems with understanding the role of graphs (Danielsen, 2008; Guttersrud, 2008; Nordby, 2008).
We saw from the interviews that it was interesting for the students to use different representation forms during their discussions about the problem. Focusing on representation form and using them in teaching process can give a variation to physics lessons. Variation is mentioned as an important keyword in characterizing a good physics lesson (Angell et al., 2004).

The role of teachers and kind of instruction in learning physics (or how teachers influence learning in physics/ science)

The students in the present study showed that they lack practice in the skill of argumentation. They showed that at the same time they had not enough scientific knowledge to reason by using different representation forms, specially, the mathematical and graphical forms. The problem can be that teachers and instructions are mostly influenced of theories that tell us that a "bright" student ought to be able to "think abstractly" and so re-create in a few weeks what our scientific history took decades and centuries to construct (Lemke, 2003).But , at the other hand rational authority from teachers' side, where teachers supply reasons and evidence for knowledge claims is a goal in science education. The reason is that a central goal of science education is to persuade students to find evidence and reasons for the ideas we hold, and to take them seriously as a guide for belief and action (Driver et al., 1998).

As Bowen and Roth (2005) have mentioned, the central practices in science is interpretation of data and graphs. In a study that Bowen and Roth (2005) have done, they examined the data and graph interpretation practices used in the reports preservice teachers produced from their own investigations. Their results suggested that teachers need more experience in engaging in data and graph interpretation practices originating in activities that provide the degree of variation in and complexity of data present in realistic investigations (Bowen & Roth, 2005).

It is a fact that improving teaching is essential to the development of physics. Teachers' knowledge is of pivotal importance in the design and conduct of teaching situations that may help students to learn science (Justi & Driel, 2005). Teachers should learn the skills of teaching about reasoning, using different representation forms and interpretation of mathematical models in physics to students.

In this study we can see the advantage of using multiple representation forms, argument/discussion and modelling in learning process of physics, for the students (see chapter 3). This is in line with Guttersrud's (2008) conclusions. He considers developing student's mathematical modelling competency as essential in physics education, and that the competency heavily depends on students' ability to handle multiple forms of representation.

Nature of science

The NOS refers to one's understanding about the social practices and organization of science and how scientists collect, interpret, and use data to guide further research (Ryder, Leach, & Driver, 1999). Using the method used by the students in the present study gives a practice in the same line of the meaning of the nature of science.

In present study the results of focus group study indicated that the main reasons for the students in giving wrong answer to the problems were:

- Lack of knowledge about physics concept.
- Weak understanding of the role of mathematics in physics.
- Not using interchanging of representation forms or using them with not complete or incorrect scientific reasoning.
- Not having a good discussion.
- Not reading completely the problem conditions.

4.2 Recommendations

How can this study to be of use?

Teacher preparation, no doubt, has a direct impact on the successful implementation of the reform efforts in the science classroom. This study is useful for teachers to encourage them in using more mathematical modelling and scientific reasoning in their instruction in physics courses. These methods give the students the possibility of using the different representation forms during their working with physics and this can be an important point which helps them to understand physics easier and better.

Representation forms

We should help students become more aware of the role of multiple representations in physics as these are important in understanding physics in better and deeper way.

Learning and understanding physics demand learning and understanding of representation forms and interchanging between them as an even more important factor. According to one of the teachers who were involved in research by Mortimer & Scott (2003), understanding something means that you can articulate it and that there isn't some kind of mysterious "brain waves" running around inside your head which allows you to think things and the most important thing in this relation is words and language. Some times students have the concept but they just can't put it into words. In this research I evaluate in detail the student-student talk of the focus group study, with a view to characterizing it, and seeing how it might support student learning.
This study indicated that it is not easy for the students to put their knowledge into words. The study also showed that the students have a limited ability to translate between mathematical and physical languages.

Mathematical modelling

Statements from the students in this study showed that the students were happy with emphasizing of mathematical modelling in their working methods during the focus group studies.

A point that statements of the students in this study indicated was that they had not enough experience in working with mathematical modelling. Another point was that they couldn't memorize the experiments they had about mathematical modelling before.

Reasoning and argumentation

It is also worthy of note according to this study that reasoning and argumentation showed to not be used often by these students during their physics courses. Nordby (2008)) who had researched about empirical- mathematical modelling in physics has also got the same conclusion from her study about the weakness of argumentation among the students in upper secondary schools. According to Kuhn (1991) the fact is that, for the overwhelming majority, the use of valid argument does not come naturally and is acquired only through practice. Therefore, it is important that students practice reasoning and argumentations processes at school and as a part of their studies.

It is important with emphasis on argumentation in the courses but it isn't sufficient by itself, students should learn concepts deeply by using mathematics in physics and different representation forms. It helps them to have a good argumentation and getting scientifically correct results of their discussions.

Mathematics in physics

In this study we found that students not only had problems with translating between different representation forms, but they particularly had partly problems with the relation between physics and mathematics and some of them had lack of mathematical skills. This point has also been found in FUN where students showed not to be good at combining formulas to solve problems (Angell et al., 2004). It seemed that the translation from a physical phenomenon to a mathematical expressions caused them problems like as here.

4.3 Conclusion

Based on this study it was indicated that teachers in physics courses don't sufficiently emphasize the role of mathematics in their teaching process. The teachers should not assume that students have enough mathematical skill. They should teach to the students the language of mathematics and physics as two aspects of the same phenomenon and not separately from each other.

This study showed that the students often, not always, are more effective in problem solving process when they work in group. An important point which was indicated was that the students didn't want to challenge each other or begin an argumentation with others during their discussions. This may be because of lack of training in reasoning based on evidence. So students should have more practice in argumentation and using different representational forms and mathematical modelling to be able to understand the nature of physics as a science. They should be taught in a way that they can have knowledge and skills to carry with them in the rest of their lives and be able to use it in their everyday lives as well as in problems they encounter professionally. Teachers also should learn to how to teach students the different representation forms of a phenomenon and how to interpret graphs in physics and details about the meaning of different component of mathematical expressions in physics. And an important point is to give students practice in the skill of argumentation and reasoning. These points must be taken into consideration in teacher preparing programs as well as in science courses.

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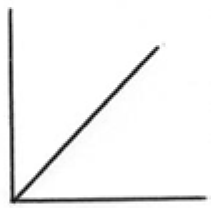
Appendices

Appendix 1 Test items

THE CAR

Some students carried out an experiment with a toy car. The students pushed the car with **constant speed** across a table. The car then fell from the table edge and down to the floor. Based on the experiment they drew the following graph:



You know these physics formulas: $v = v_0 + at$ and $s = v_0 t + \frac{1}{2}at^2$.

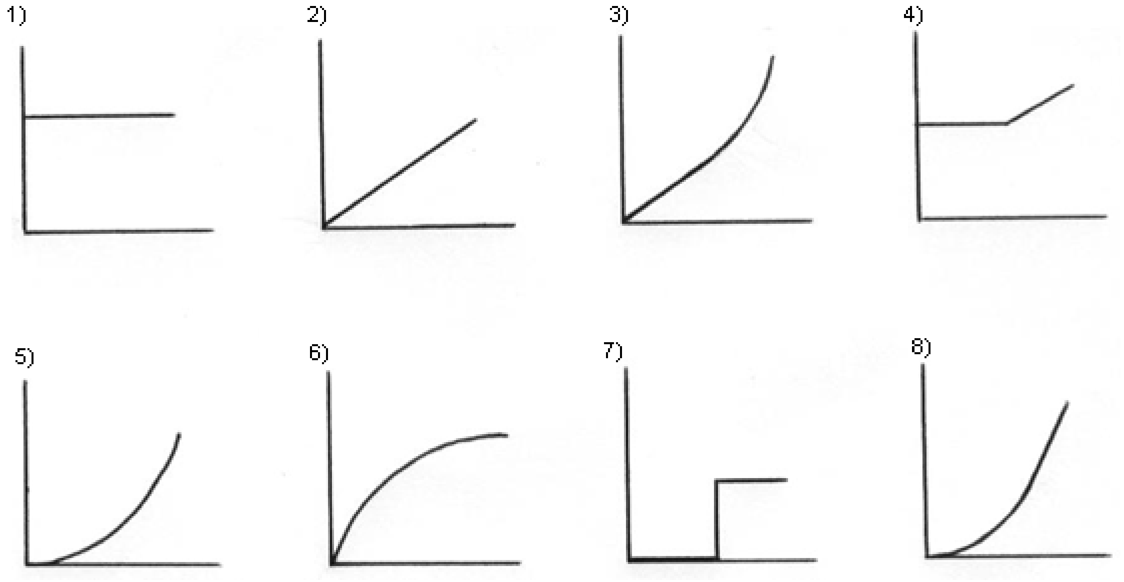
Question 1: THE CAR *U12Q01 concept/graph; evaluate – 0 1 2 3 9*

Decide for each statement if it is correct. Circle "Yes" or "No" for each.

Statement	Is the statement correct?
The graph can show the car's **displacement** as a function of time when the car moves with constant speed across the table. Q01_1	Yes / No
The graph can show the car's **acceleration** as a function of time when the car moves with constant speed across the table. Q01_2	Yes / No
The graph can show the car's **speed** as a function of time when the car is in free fall. Q01_4	Yes / No

Question 2: THE CAR

Which of the eight graphs below show the toy car's acceleration, speed and displacement respectively as a function of time for the car's entire motion (both when it moved across the table and when it was in free fall)? (Respond by filling in the vacant spaces in the sentences below!)



a) Graph number ___ shows **acceleration** as function of time.

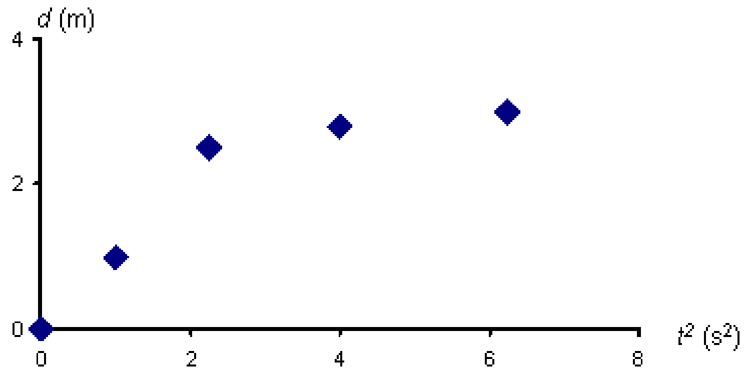
b) Graph number ___ shows **speed** as function of time.

c) Graph number ___ shows **displacement** as function of time.

The students attached a rope to the car and tried to pull it with constant acceleration across the floor. The students measured displacement and time, and they plotted displacement as a function of the time squared.

The students knew that displacement may be written as $s = ½\, at^2$ when the initial speed is zero.

d(m)	t(s)	t^2(s^2)
0	0	0
1,0	1,0	1,00
2,5	1,5	2,25
2,8	2,0	4,00
3,0	2,5	6,25



Question 3: THE CAR

U12Q05 concept/graph; conclude and com.
– 01 02 03 04 05 06 07 08 11 12 19 21 22 99

May the students conclude that the acceleration was constant? Explain your answer.

....

....

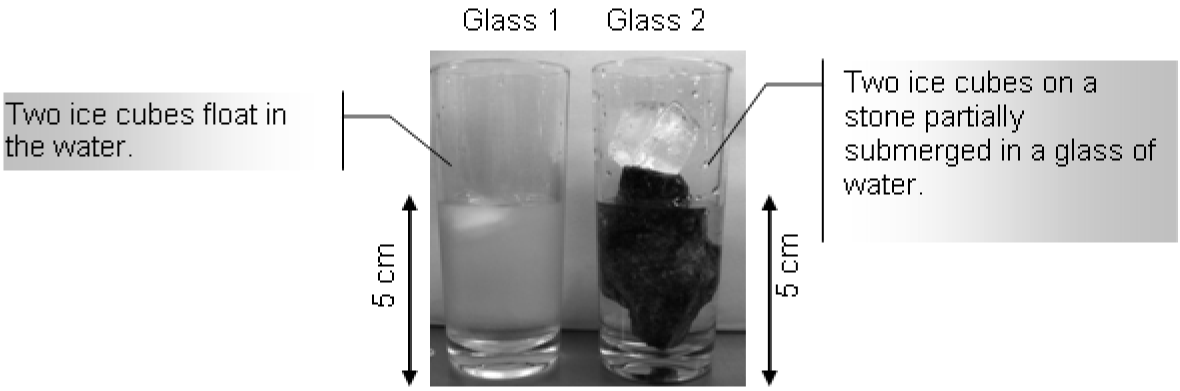
SEA LEVEL

Some students wanted to study how the melting of ice around The South Pole and in the areas around The North Pole influences the sea level.

The students filled a glass (glass 1) with water. When they put two ice cubes into the glass, the water level was 5 cm. The students put a stone into an identical glass (glass 2). They put two ice cubes on top of the stone and filled the glass with water until the water level was 5 cm there as well.

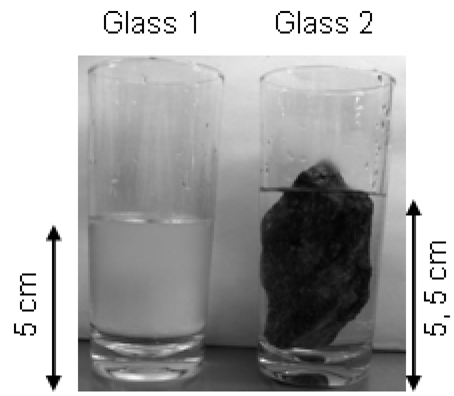
At the North Pole there is no land under the ice, but at The South Pole there is. The stone represents these territories. Glass 1 thus represents The North Pole, while glass 2 represents The South Pole.

BEFORE MELTING



The picture below was taken after the ice cubes had melted:

AFTER MELTING



Question 9: SEA LEVEL

U14Q01 math/exper; identify/apply – 0 1 9

Assume that the ice is melting with a constant rate. Which mathematical expression describes the water level (y) in glass 1 and glass 2 while the ice melts?

A Glass 1: $y = b$, glass 2: $y = ax + b$

B Glass 1: $y = ax + b$, glass 2: $y = b$

C Glass 1: $y = b$, glass 2: $y = ax$

D Glass 1: $y = ax$, glass 2: $y = b$

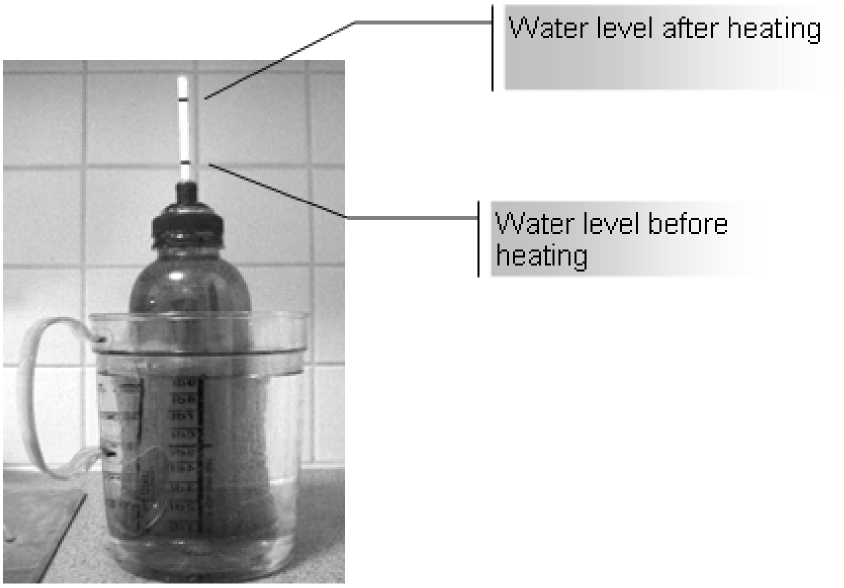
Question 10: SEA LEVEL

U14Q02 concept/math; decide – 0 1 9

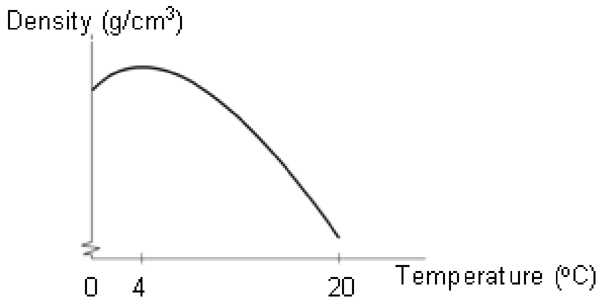
What does the x in the expressions in the previous question refers to?

A The melting speed of the ice
B The original water level in the glass
C The temperature of the water in the glass
D The time from the ice began to melt

The students filled a bottle with cold water (0 ºC). They made a hole in the cap and attached a thin straw (see the photography). They placed the bottle in a container with water (20 ºC). The lower line on the straw shows the water level before the bottle was placed into the warm water, while the upper line shows the water level in the straw after the water in the bottle and container had reached the same temperature.



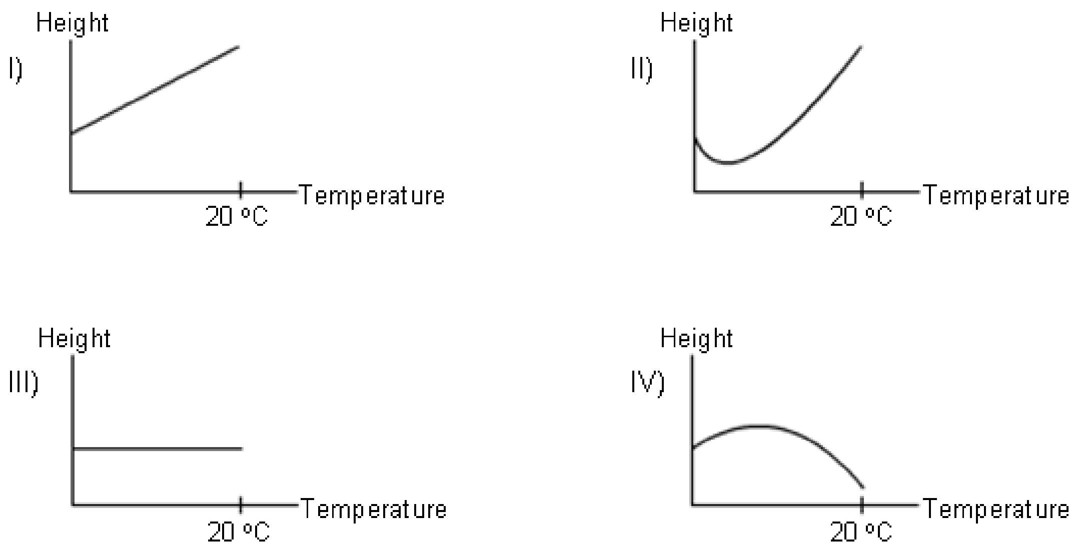
The figure below shows the density of water as a function of temperature:



Question 11: SEA LEVEL

U14Q03 graph/exper; decide – 0 1 9

Which of the graphs below shows the height of the water in the straw as a function of the temperature of the water in the bottle?



A Graph number I
B Graph number II
C Graph number III
D Graph number IV

Question 12: SEA LEVEL

U14Q04 math/graph; identify/apply – 0 1 9

In the frame below there are some mathematical expressions numbered 1-12.

<u>Note: the constants a, b and c are positive and greater than zero:</u>

1) $y = -ax^2+bx-c$	2) $y = -ax^2+bx+c$	3) $y = ax^2-bx+c$	4) $y = ax^2+bx+c$
5) $y = ax^2+bx$	6) $y = -ax^2+bx$	7) $y = -ax^2-bx$	8) $y = x^2+x$
9) $y = ax+b$	10) $y = ax$	11) $y = x$	12) $y = a$

Which expressions express the graphs above best?

a) Graph **I** is best expressed by expression no._______.

b) Graph **II** is best expressed by expression no._______.

c) Graph **III** is best expressed by expression no._______.

d) Graph **IV** is best expressed by expression no._______.

Question 13: SEA LEVEL

U14Q05 concept/exper; conclude and com.

– 01 02 03 04 11 12 13 21 22 23 29 99

Write down how the sea level can change if the average temperature on Earth increases. Use the information from the experiments with **glass 1 and 2** and the **bottle with the straw**:

……

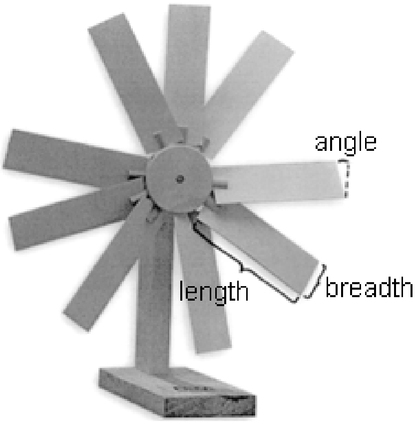
……

……

WINDPOWER

Some students built a small windmill and attached blades with different length, breadth and angle to the mill. They used a fan with two speeds (high and low) as a wind source.

The students connected a generator to the mill to produce electric current, and they used a voltmeter to measure the mill's ability to provide electric potential energy. The diagram shows the results of students' measurements.

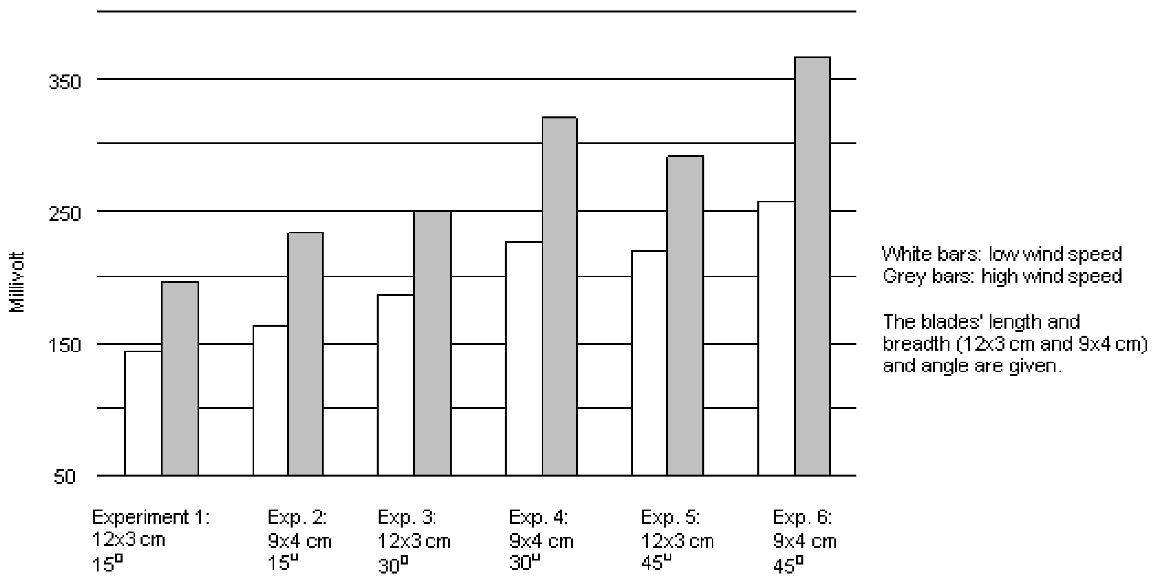


The students had three hypotheses they wanted to test:

1) A long blade produces more energy than a short at the same wind speed.

2) An angle of 45^0 is the most effective of all angles between 0 and 90^0.

3) Low wind speed provides less energy than high wind speed.



Question 25: WIND POWER

U05Q02 concept/exper; decide – 0 1 9

To test their hypotheses the students had some variables (blades' length, wind speed) and some constants (blades' surface area).

What explained BEST why the students kept the blades' surface area constant?

A To keep the energy production the same at high and low speed.
B To keep the blades' energy production the same for long as for short blades.
C To keep the wind force on the blades the same at high and low speed.
D To keep the wind force on the blades the same for long as for short blades.

Question 26: WIND POWER

U05Q04 graph/exper; evaluate – 0 1 9

Look at the students' measurements and decide whether the hypotheses **1** and **3** should be kept or not. Circle "Yes" or "No" for each.

Hypothesis	**Should the hypothesis be kept?**
A long blade produces more energy than a short at the same wind speed (hypothesis **1**).	Yes / No
Low wind speed provides less energy than high wind speed (hypothesis **3**).	Yes / No

Question 27: WIND POWER

U05Q05 graph/exper; categorize – 01 02 (03) 04 11 12 99

Hypothesis 2: "An angle of 45^0 is the most effective of all angles between 0 og 90^0".

Write down (in the vacant spaces) the numbers for three experiments at "high speed" that the students may compare to decide whether the data so far strengthen or weaken hypothesis 2:

Experiment number ____, ____ and ____.

Question 28: WIND POWER

U05Q06 graph/exper; conclude and com. – 01 02 03 04 05 06 11 21 22 99

Do the students have sufficient data to decide whether hypothesis 2 should be kept or rejected? Explain your answer.

....

....

Appendix 2 Scoring guides

MULTIPLE CHOICE ITEMS (KEY RESPONSES):
9A, 10D, 11B, 25D

VECTOR ITEMS (CORRECT ANSWERS):
1: Yes, No, Yes
26: No, Yes.

SHORT CONSTRUCTED RESPONSE ITEMS:
2a-c: correct answers: 7, 4, 3.
12a-d: correct answers: 9, 3, 12, 2.
27: correct answer: 1, 3, 5 OR 2, 4, 6.

EXTENDED CONSTRUCTED RESPONSE ITEMS:
Note: Give as many points as possible. If a response fits several response categories (codes) at the same credit level, score with reference to the first type of answer appearing in the response.

THE CAR SCORING 5 (QUESTION 3)

Full credit

Code 21: Refers to acceleration **not** being constant on the grounds that the dots not lie along a straight line or equivalent (*qualitative solution*).

- No, because the numbers are not a linear regression by graphical representation
- No, then the curve would have ascended equally all the way.
- No, from the graph one sees that it (*acceleration)* does not increase at the same rate but gets flatter.
- Not constant, as the graph bends.
- No, the graph "breaks".
- If the acceleration was constant the graph would have been a straight line.
- If the acceleration was constant the graph would have been a long line.

Code 22: Refers to acceleration **not** being constant on the grounds that the increase in speed is not constant, OR that the acceleration, if calculated for each point, is not constant (*quantitative solution*).

- No. The acceleration decreases. If we use the formulae $a = 2s/t_2$ on the numbers in the table we see that a first increases then decreases.
- The acceleration was not entirely constant. The number of metres per time does not increase constantly.
- No because the speed increases the first 2m and decreases after that.
- No. If one uses the formula to calculate in the different points, it is not the same everywhere.

Partial credit

Code 11: Refers to acceleration **not** being constant on the grounds that it decreases (only partially correct answer).

- No, because the acceleration decreases.
- No, because the acceleration decreases for every point and approaches constant speed.

Code 12: Refers to acceleration **not** being constant on the grounds that the graph is not parabolic or exponential.

- It is not constant then the dots would have made a parabola rising upwards.

Code 19: Other partially correct answers

- No, at the end the car moved almost nothing.
- No, because the graph varies.
- No, it can not be that when the graph is so inconsistent.
- No, because s and t_2 do not increase in parallel.
- No, the measurements are not proportional.
- No, a is not always the same.

No credit

Code 01: Refers to acceleration **not** being constant on the grounds that the speed is not constant OR that the acceleration is different from zero.

- No they can not. The relationship between s and t is not the same in the measurements. The acceleration does not become constant.
- No, the acceleration was not constant because the distance travelled every half second varies (***This is true when the acceleration <u>is</u> constant***).
- No, they may have pulled the car unevenly.
- No, because then the sum of the forces they exerted had been equal to zero, if it was constant.
- No, the speed increased.

Code 02: Refers to acceleration **not** being constant on the grounds that the graph is not constant/parallel with x-axis, or similar responses.

- No, then the curve would have been constant.
- No, because the graph has slope different from 0.
- No, because the graph rises (the numbers rise).

Code 03: Refers to acceleration **not** being constant on the grounds that it increases (explicitly).

- No, because the acceleration increased.
- No, the acceleration increased when they started to pull.

Code 04: Refers to acceleration **not** being constant initially but becoming constant gradually.

- No, from the graph you see that the acceleration is not constant before after 2 seconds.

Code 05: Refers to acceleration being **1**) constant until 2 seconds with or without commenting that it decreases OR that the acceleration **2**) decreases after 2 seconds, OR that it **3**) first increases then later decreases.

- No, from the graph it was even acceleration in the beginning, but it slows down again when t_2 equals 4.
- The acceleration is constant from 0 to 2 seconds (***i.e. it is not constant throughout***).

Code 06: Refers to acceleration **not** being constant without explanation.

- No, it did not have constant acceleration.
- No, you can see from the measurements that it is not constant.
- No, because the car has varying accel.
- No. If you look at the dots in the diagram it is not constant.
- No, not from this graph.

Code 07: Refers to acceleration being constant.

- Yes, from 0-2 and from 2-6 seconds.
- The acceleration is always constant.

Code 08: Other answers

- The acceleration was not constant because you do not mange to pull the rope so that it becomes steady speed, it is a bit by fits and starts, and that is shown in the dots.
- No, then they would have another curve.
- No, because then the graph would have looked different.

Code 99: Missing

s(m)	t(s)	t^2	$a=2s/t^2$
0	0	0	-
1,0	1,0	1,00	2,00
2,5	1,5	2,25	2,22
2,8	2,0	4,00	1,40
3,0	2,5	6,25	0,96

SEA LEVEL SCORING 5 (QUESTION 13)

Three aspects:
1) The sea level **rises** because the ice at The South Pole melts and/or glaciers melt.
2) The sea level **falls** until all melted water have reached a temperature at 4 $_0$C.
3) The sea level **rises** because the water expands/the density decreases (above 4 $_0$C).

Full credit

Code 21: Aspects **1, 2 and 3** correct.

- The sea level will rise when the ice at The South Pole melts. On the other hand it will not rise when the ice melts at The North Pole. The water level will sink until the water reaches 4 degrees, and then it will rise after it has passed through this temperature. This is because water has lowest density at 4 degrees.

Code 22: Aspects **1** and **3** correct only.

- The sea level will rise a little bit, not due to melting at the North Pole, but due to melting at The South Pole and that hotter water takes more space.
- The sea level increases, <u>glaciers may melt</u> and <u>the water level rises when the water becomes hotter.</u> The South Pole will get territories coming up of the water.

Code 23: Aspects **2** and **3** correct only and possibly that the sea level rises because ice (at the **poles** or The North Pole) melts.

- The sea level will sink if it is colder than 4 degrees, but above that the sea level will rise.
- The sea level will first sink because the density decreases, consequently the sea level will rise after the temperature has reached 4 degrees, and if the warming continues it will rise even more.
- If the temperature increases, the sea level will <u>first sink</u> (as water is heaviest at 4 degrees), but then the poles will melt even more and the water rises past the normal.

Code 29: Other correct answers (including answers referring to aspects **1** and **2**).

- The sea level may increase because the ice at The South Pole melts. The sea level may also sink because the density of the water increases and it takes less space (***aspects 1 and 2***).
- If the initial temperature of the sea water is zero degrees the sea level will first sink then rise above the initial level. According to the experiment with glass 1 and 2 the sea level will further rise the most at The South Pole (***aspects 2 and 3, but wrong interpretation of the experiment concerning the glasses***).
- The sea level will rise if the temperature increases to a point where the ice at The South Pole melts. The density of the water may also affect the sea level (***does not specify rise (aspect 3)/decrease (aspect 2)***).

Partial credit

Code 11: Aspect **1** correct only (and possibly wrong interpretations of the link between temperature and density).

- If the ice in the Antarctic and Greenland melts due to higher temperature the sea level will rise dramatically.

Code 12: Aspect **3** correct only and possibly that the sea level rises because ice (at the **poles** or The North Pole) melts.

- The sea level rises if the temperature increases because the water expands at higher temperature.

- The sea level will rise because the water becomes warmer and expands in addition to a rise due to melting of The North Pole ice.

Code 13: Aspect **3** correct only but states that the experiment concerning the glasses make evident that the sea level only rises OR rises the most around The South Pole/some places.

- When the temperature increases the ice at the poles melts and the water is heated. We saw from glass 2 that the water level around The South Pole rises the most because there is firms land there. When the temperature increases in the water the water becomes less dense and the molecules move with more space between every single molecule and the water ”widens out” and the sea level rises.

No credit

Code 01: Refers to the sea level rising because ice (at the **poles** or The North Pole) melts.

- Ice from the poles may melt and consequently increase the amount of water in the sea.

Code 02: Refers to the sea level rising around The South Pole/some places.

- When the mean temperature on the Earth increases the sea level will rise. That is the case at The South Pole. At the North Pole the sea level will stay the same.
- It may increase some places and decrease other places.

Code 03: Refers to rising sea level without explanation.

- The sea level will rise as in the bottle.
- The sea level rises. People have to move.

Code 04: Other answers (including wrong explanations)

- When the temperature increases the water level will increase. If there are rocks in the water it will be even higher than if there are no rocks. This is because it adds more volume to the water.
- The ice that floats in the sea will not change the sea level when it melts. But the ice above sea level will (***unclear whether the student refers to the 1/10 of an ice cube visible or ice on land)***.

Code 99: Missing

WINDPOWER SCORING 5 (QUESTION 27)

Note: Code 11 and 12 refer to experiments where the blades' angle varies while their length and width are kept constant. Code 01 refers to experiments where the blades' angle varies while their length and breadth are not kept constant. Code 02 refers to experiments where neither the angle varies nor length or breadth is kept constant.

Full credit

Refers:

Code 11: Refers to experiments 1, 3 and 5 only.
Code 12: Refers to experiments 2, 4 and 6 only.

No credit

Code 01: Refers to experiments 1, 3 and 6 OR 1, 4 and 6.

Code 02: Refers to other combinations consisting of three of the six experiments.

(Code 03: Code 03 was applied to respondents who referred to the experiments 4, 5 and 6. It was subordinated to and merged with code 02.)

Code 04: Other answers
- 1, 3
- 4, 5, 7
- 1, 33, 7
- 40, 50, 60

Code 99: Missing

WINDPOWER SCORING 6 (QUESTION 28)

Full credit

Code 21: Refers to lack of data above 45 degrees and not able to decide.
- No, they should have tried angles between 45 and 90 degrees.

Code 22: Refers to keeping the hypothesis for the time being, but that they should explore angles above 45 degrees.
- Yes, they should keep it. One sees an obvious rise in energy production in the increase from 0 – 45 grader. They should test 45 – 90 degrees.

Partial credit

Code 11: Refers to insufficient data and not able to decide (not explicit that they should explore angles above 45 degrees).
- No, they do not have enough data. It should have been tested more than 3 angles.
- No, because they only tested 3 angles.
- No, they only tested 3 different angles and can not rule out the rest of the angles.

No credit

Code 01: Refers to lack of data with other explanation.
- No, they need to take more measurements on among other 30 degrees, I believe.
- Should have more data. Too uncertain with only one experiment which is right.
- No, they have contradictive data.
- No, because they can not measure it.
- No, they should have included data for angles above 90 degrees to.
- No, they need to do more experiments (***almost code 02***).

Code 02: Refers to lack of data without explanation.
- No, they do not have data to decide (***repeats stem***)
- No

Code 03: Refers to data being sufficient to decide with or without explanation.
- Yes, because they see that the wind speeds on a wide blade increase with the angle.
- Yes, because they have tested several different angles with the same length and width on the blade for several velocities.
- Yes

Code 04: Refers to keeping the hypothesis OR that the hypothesis is “correct” with the explanation that the angle 45 degrees produces most energy.
- They can keep the hypothesis. The most effective angle is 45 degrees. It is then it is produced most.

Code 05: Refers to keeping OR rejecting the hypothesis, that the hypothesis is correct OR not correct with other explanation (than in code 22 and 04).
- They have enough data to keep the hypothesis because it appears not to be a coincidence.
- Yes, they have enough data; they can see that hypothesis 2 is correct.
- Yes, they must keep hypothesis 2 because the comparisons of the experiments 4 and 6 show that it is correct.
- 3 measurements with the same result are enough to keep the hypothesis.
- An angle of 30 degrees produced more energy if the blades were 9x4 than an angle at 45 degrees with12x3, reject.
- Keep
- Reject

Code 06: Other answers

- Well yes and no (…)
- Both yes and no (…)

Code 99 Missing

Appendix 3 Interview guide

Innledning

Hei. Jeg heter Mozhgan Mahmoudy og holder på med master i fysikkdidaktikk på Universitet i Oslo.
Oppgaven min er knyttet til et prosjekt som heter FYS 21. Prosjektets hovedmål er å jobbe med bruk av matematiske modellering av naturfenomener og å vurdere hvordan å bruke modeller kan hjelpe elevene med å forstå fysikkfaget på skolen.

Dere får tre oppgaver. Dere skal få se på hver oppgave i 5 minutter og etter det begynner dere å løse oppgavene i felleskap, samtidig som dere diskuterer oppgavene med hverandre. Vi tar en oppgave av gangen.

Vi er interessert i å høre hvordan dere tenker når dere løser oppgavene. Derfor vil vi at dere snakker sammen, diskuterer og kommer fram med egne tanker og ideer. Siden alt dere sier skal tas opp på tape, er det viktig at dere forklarer om deres tenkemåte.

Jeg vil ikke stille mange direkte spørsmål direkte, men griper inn for å sette dere på sporet hvis det blir nødvendig.

Etter at dere er ferdige med alle oppgavene, vil jeg stille noen få spørsmål angående oppgavene.

Jeg kommer til å ta samtalene opp på kassett. Jeg skal bruke den i master oppgaven min og alt jeg skriver vil bli anonymt.

Hvis noen av dere ikke liker at jeg skal ta samtalen opp på kassett, har dere lov til å gå.

Hvis det er noe dere lurer på kan dere spørre nå.

Da tror jeg bare vi begynner.

Generelle spørsmål

- Hvordan var der å arbeide med disse oppgavene?
- Hva var lett eller vanskelig?
- Hva synes dere at dere lærer av disse oppgavene?
- Har dere sett oppgaver før som ligner på disse oppgavene? (Hvis nei: Hva var annerledes her?)

I fysikken er det å lage modeller av virkeligheten viktig.

- Hva forbinder dere med ordet ”modell” i fysikken?
- I oppgavene dere nettopp løste, var modeller av fysiske fenomener beskrevet med ord, med grafer og med matematiske formler. Hvordan synes dere er å se sammenhengen mellom disse ulike måtene å beskrive samme fenomen på?

Appendix 4 Code list

Here is the list over the codes used in this study

Family A:
A_Communic_aut/single
A_Communic_aut/multi
A_Communic_Intui/multi
A_Communic_Intui/single

Family B:
B_Content_emp/descr
B_Content_emp/explan
B_Content_theoret/general
B_Content_theoret/descry
B_Content_theoret/explan

Family C:
C_interv_cumulative
C_interv_disputational
C_interv_exploratory

Family D:
D_argTyp_math
D_argType_physics
D_argType_everyday

Family E:
E_multi_ConcepExp_aut
E_multi_ConceptExp_intui
E_multi_ConcepGrap_aut
E_multi_ConcepGrap_intui
E_multi_ConcepPic_aut
E_multi_ConcepPic_intui
E_multi_ExpGrap_aut
E_multi_ExpGrap_intui
E_multi_ExpPic_aut
E_multi_ExpPic_intui
E_multi_GrapPic_aut
E_multi_GrapPic_intui
E_multi_MatExp_aut
E_multi_MatExp_intui
E_multi_MatGrap_aut
E_multi_MatGrap_intui
E_multi_MatPic_aut
E_multi_MatPic_intui